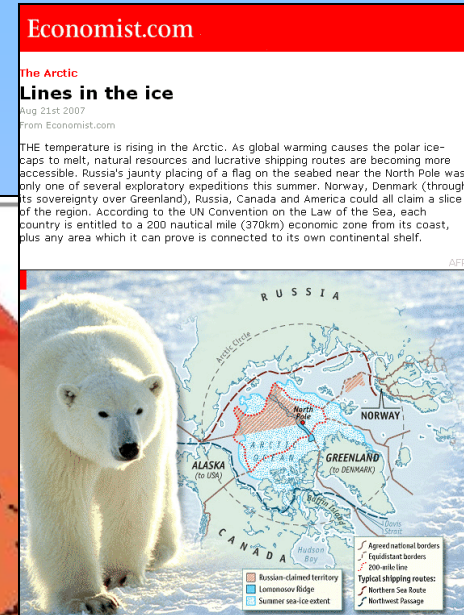
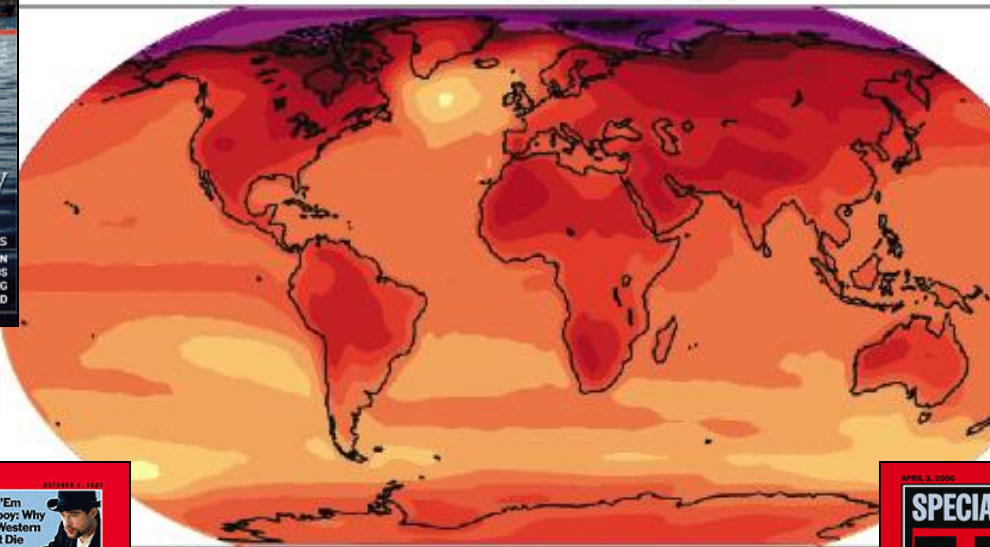
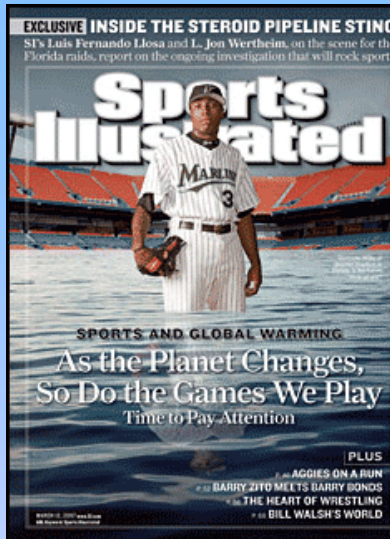


POLAR SNOW AND ICE:

Indicators of past and current climate

Don Perovich and Jackie Richter-Menge, CRREL

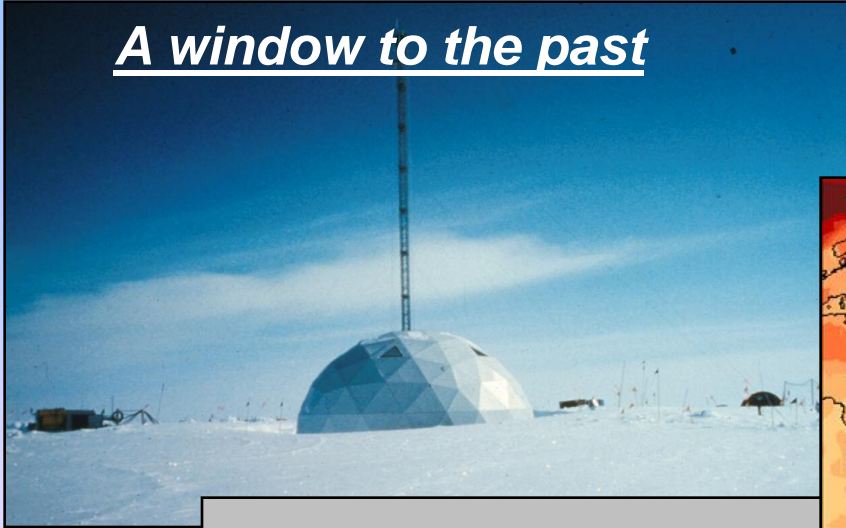
CLIMATE CHANGE IN THE NEWS



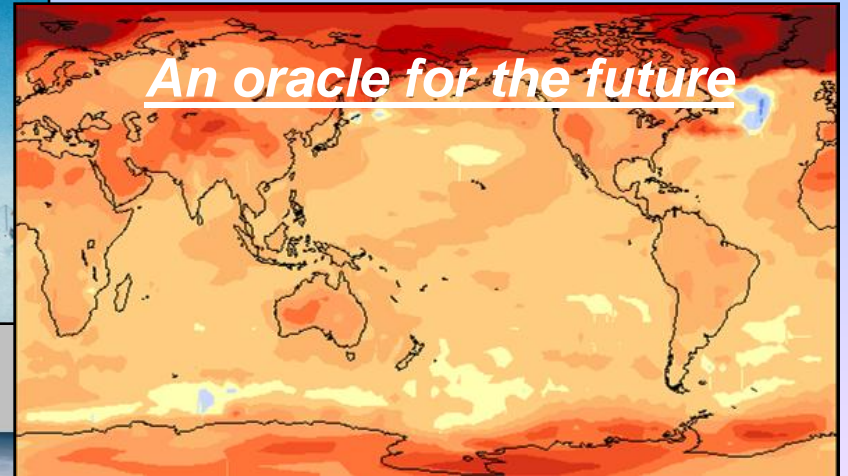
CLIMATE CHANGE:

View through a prism of ice

A window to the past



An oracle for the future

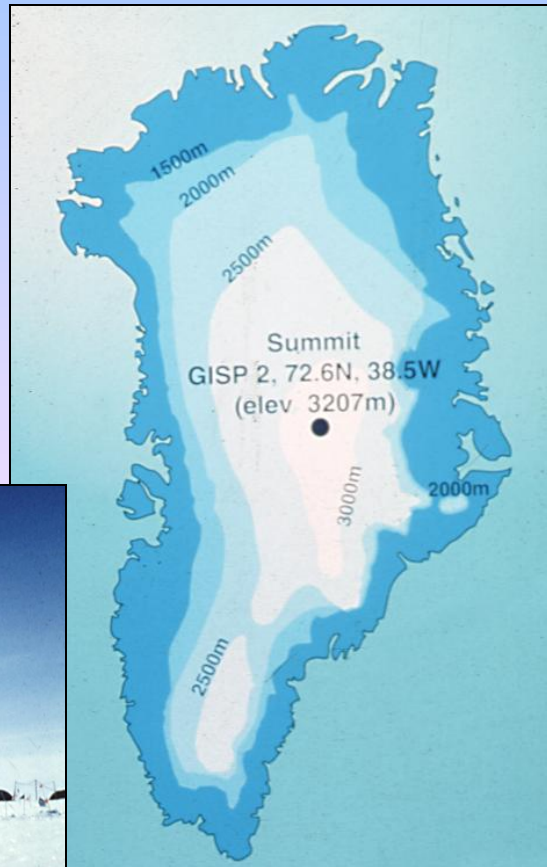
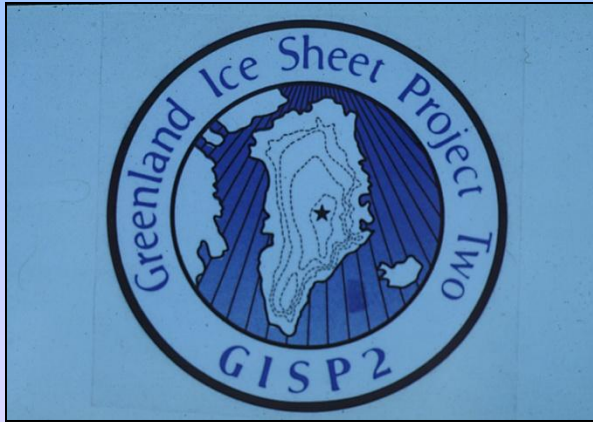


An indicator of current change



WINDOW TO THE PAST: Paleoclimatology

Deep Glacial Ice Cores



- Fresh Ice
- No melting
- Constant accumulation
- Little deformation
- 2-miles deep
- One of the longest historical record of climate
- Represents over 100,000-year period
- Pre-industrial

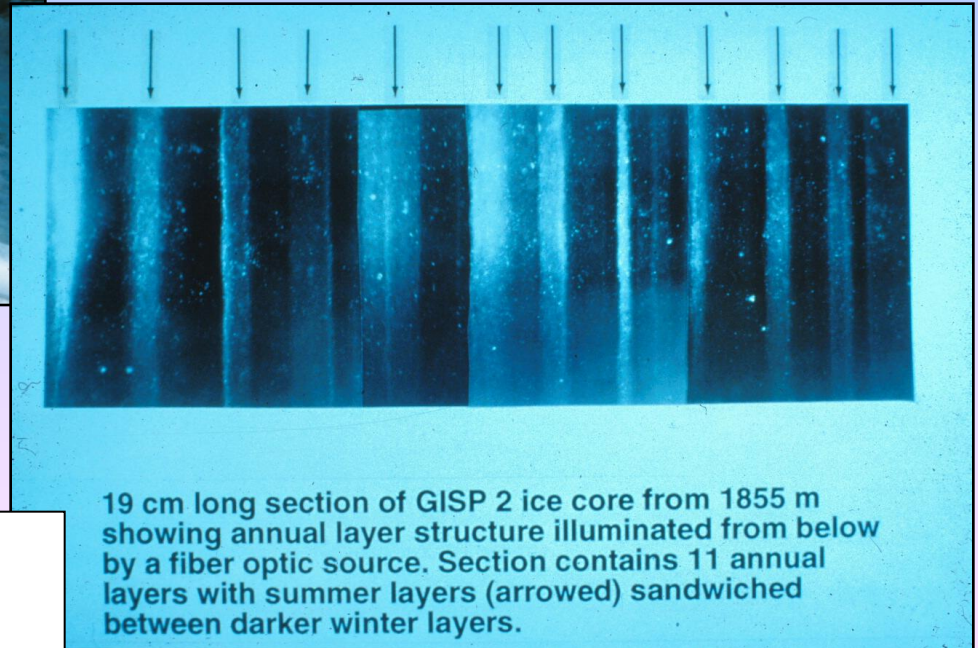


Accumulation Only!



WINDOW TO THE PAST: Paleoclimatology

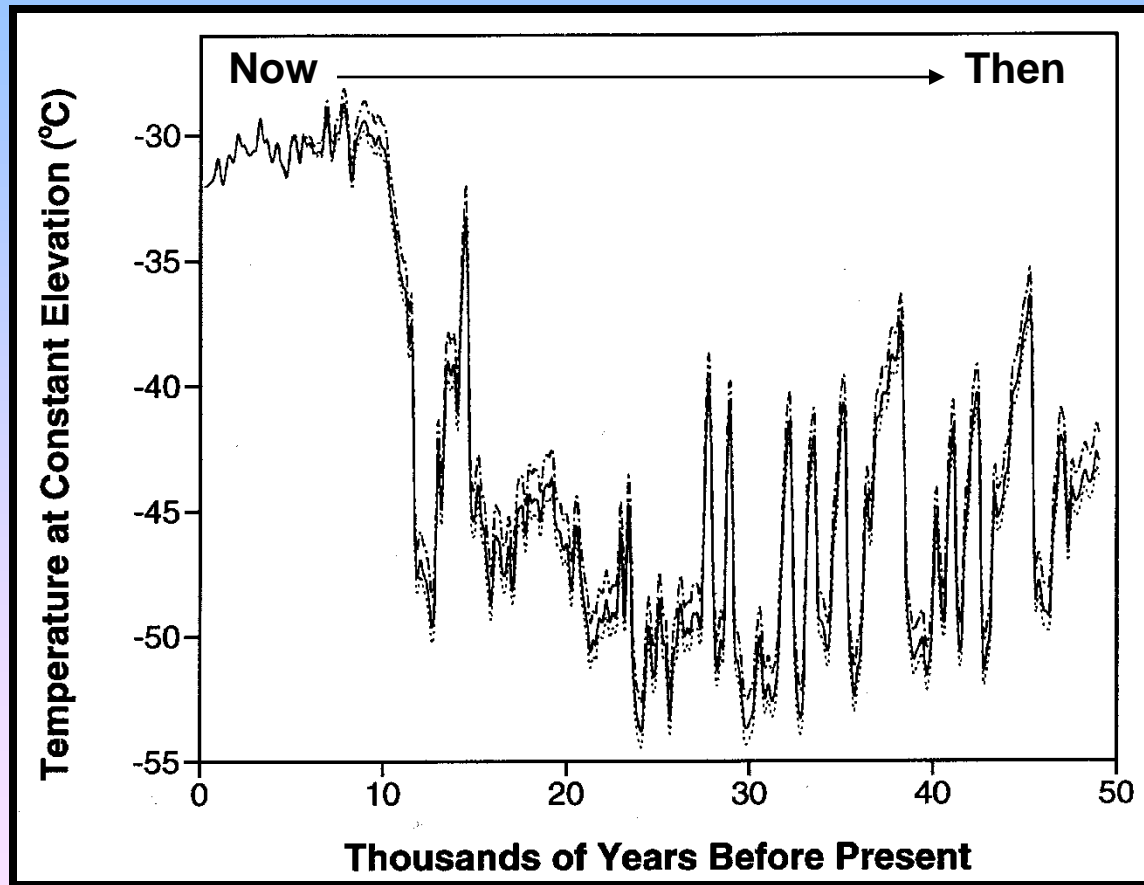
Deep Glacial Ice Cores



- Light and dark layer = 1 year
- Think: Tree ring
- Thickness proxy for temperature
- Thinner the band, colder the temp

WINDOW TO THE PAST

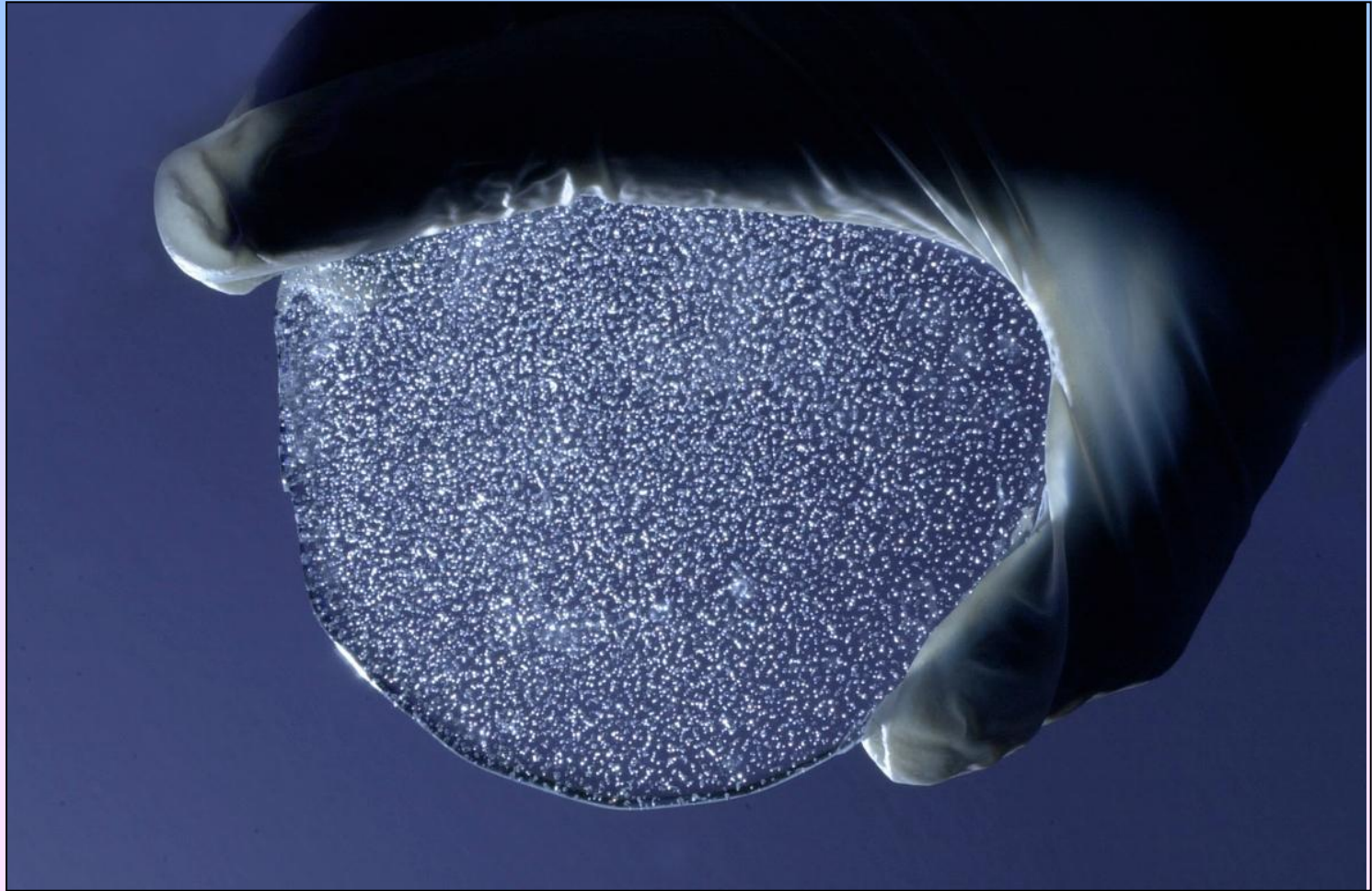
Results from GISP core



Natural periods of rapid and significant change in temperature

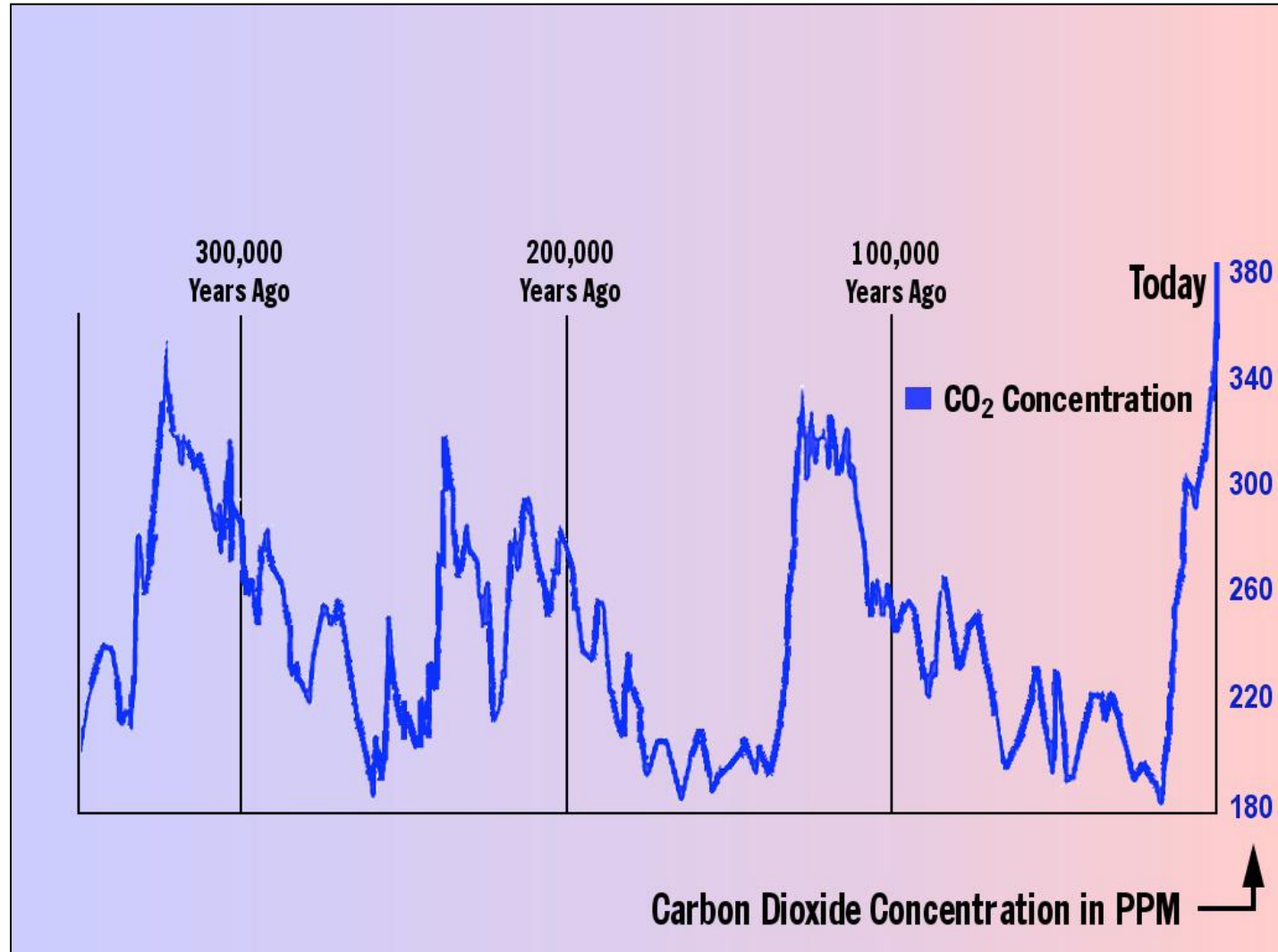
WINDOW TO THE PAST

Atmospheric Content



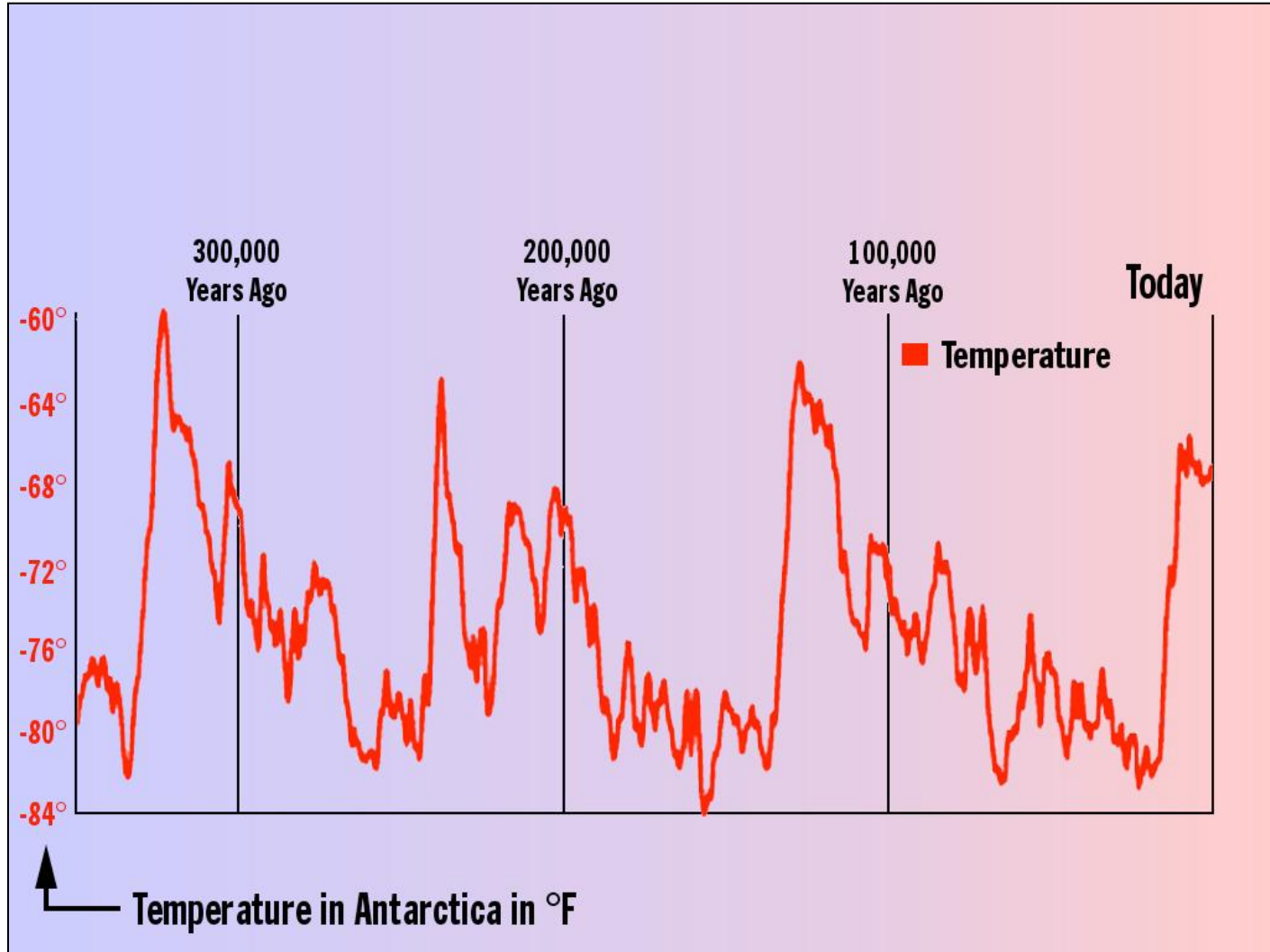
WINDOW TO THE PAST

CO₂ and temperature



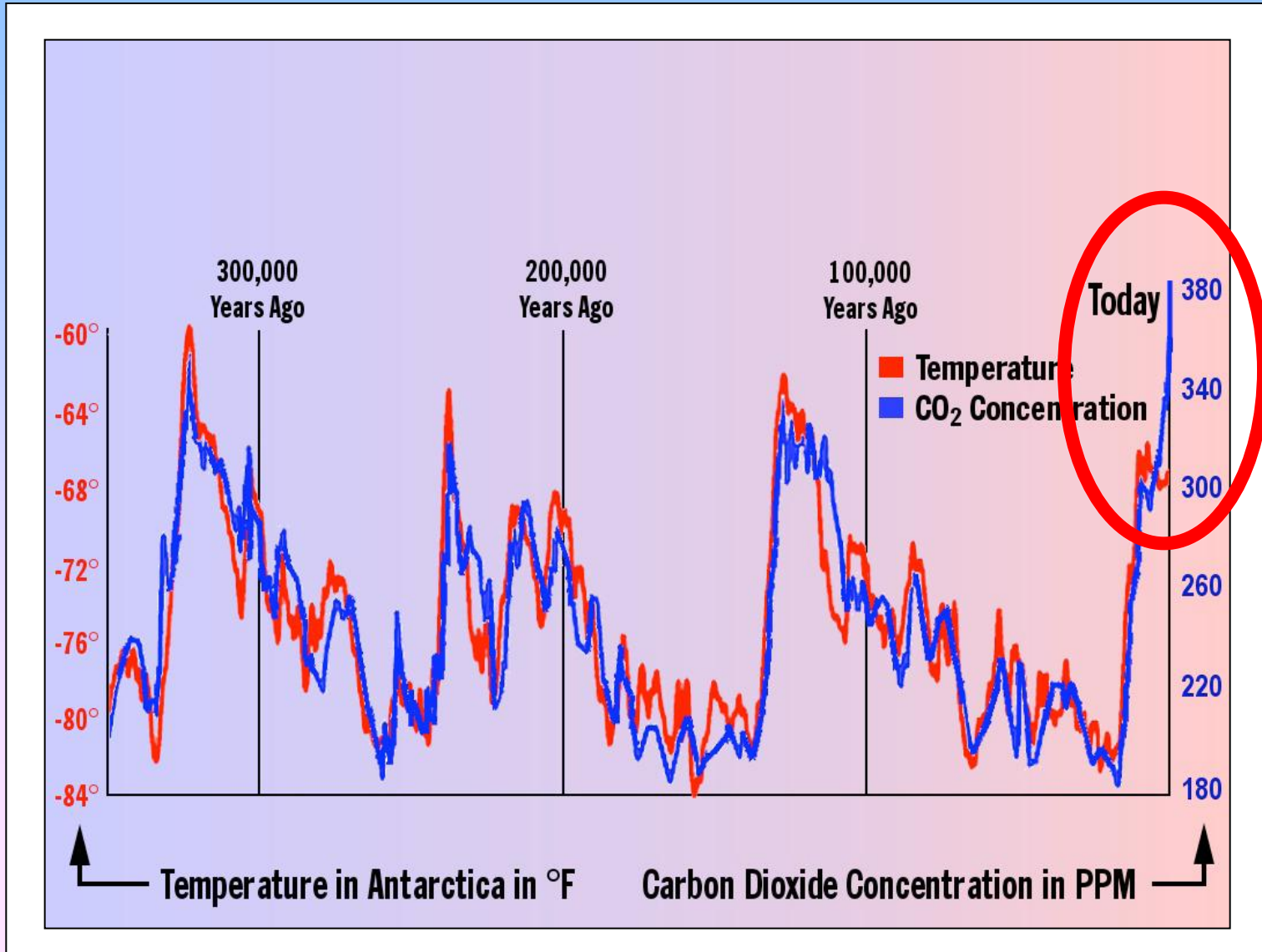
WINDOW TO THE PAST

CO₂ and temperature



WINDOW TO THE PAST

CO₂ and temperature



WINDOW TO THE PAST

Summary

- **Deep glacial cores key resource for historical perspective**
- **Large and sudden swings in regional temperatures have occurred in the past**
- **Temperature and CO₂ content closely linked**
- **Current CO₂ levels alarmingly high**
- **Experimenting with Mother Nature**

Want ads – 1910

Notice:

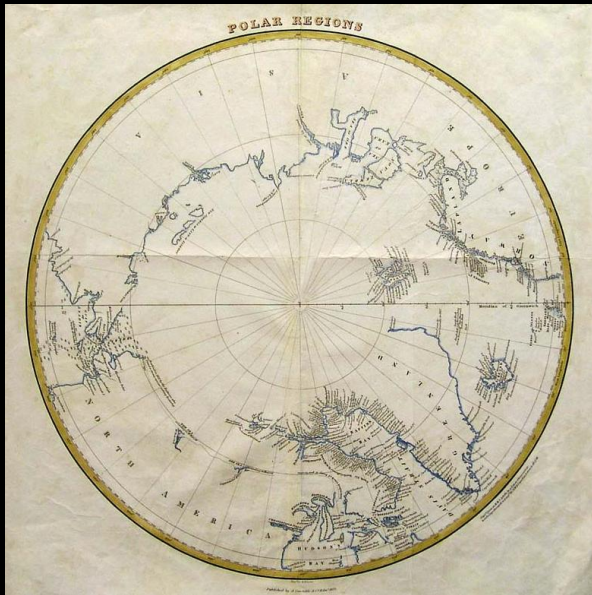
Men wanted for hazardous journey.
Small wages, bitter cold.
Long months of complete darkness.
Constant danger. Safe return doubtful.
Honour and recognition in case of success.

- Ernest Shackleton



They were driven by a map

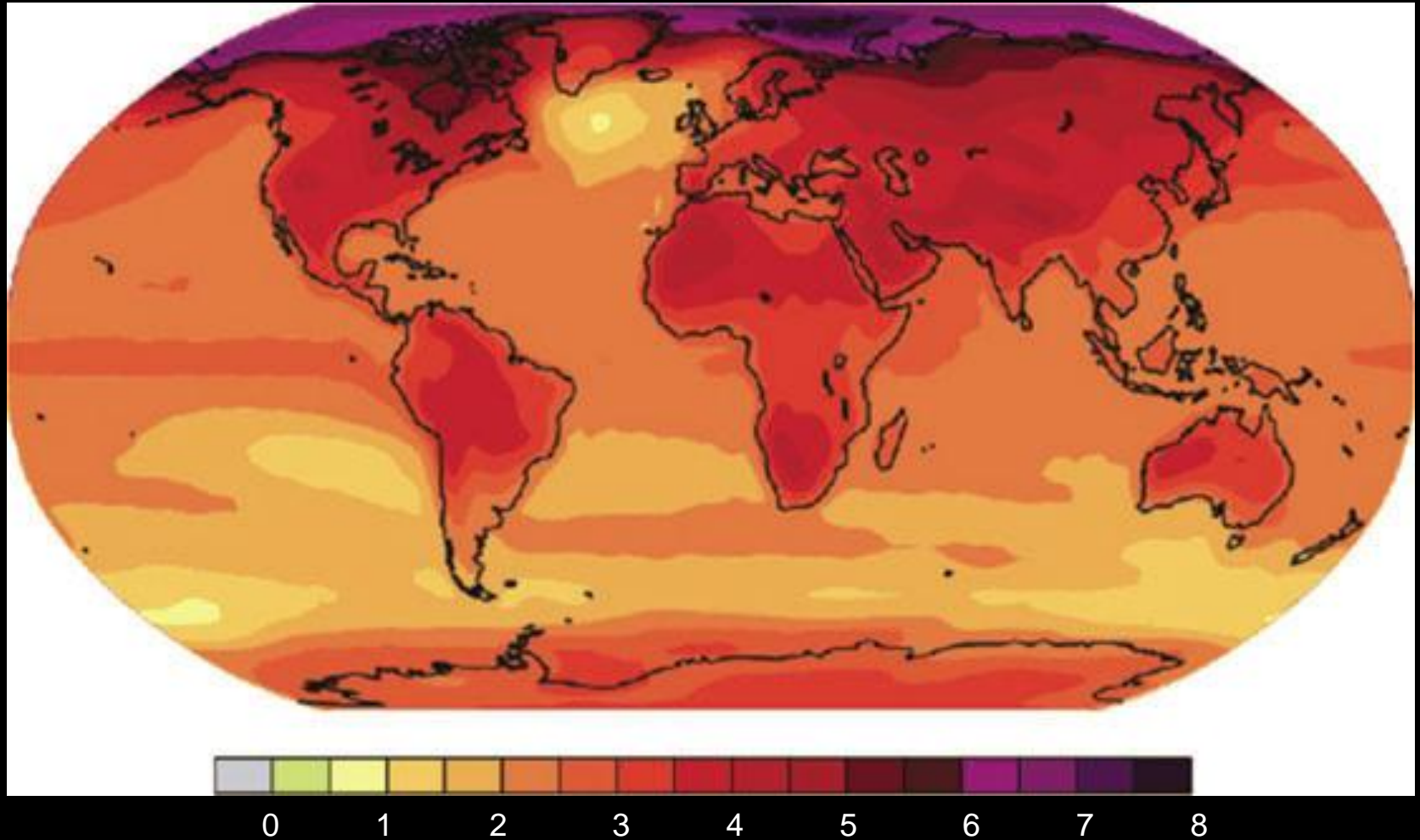
A map with blank spaces



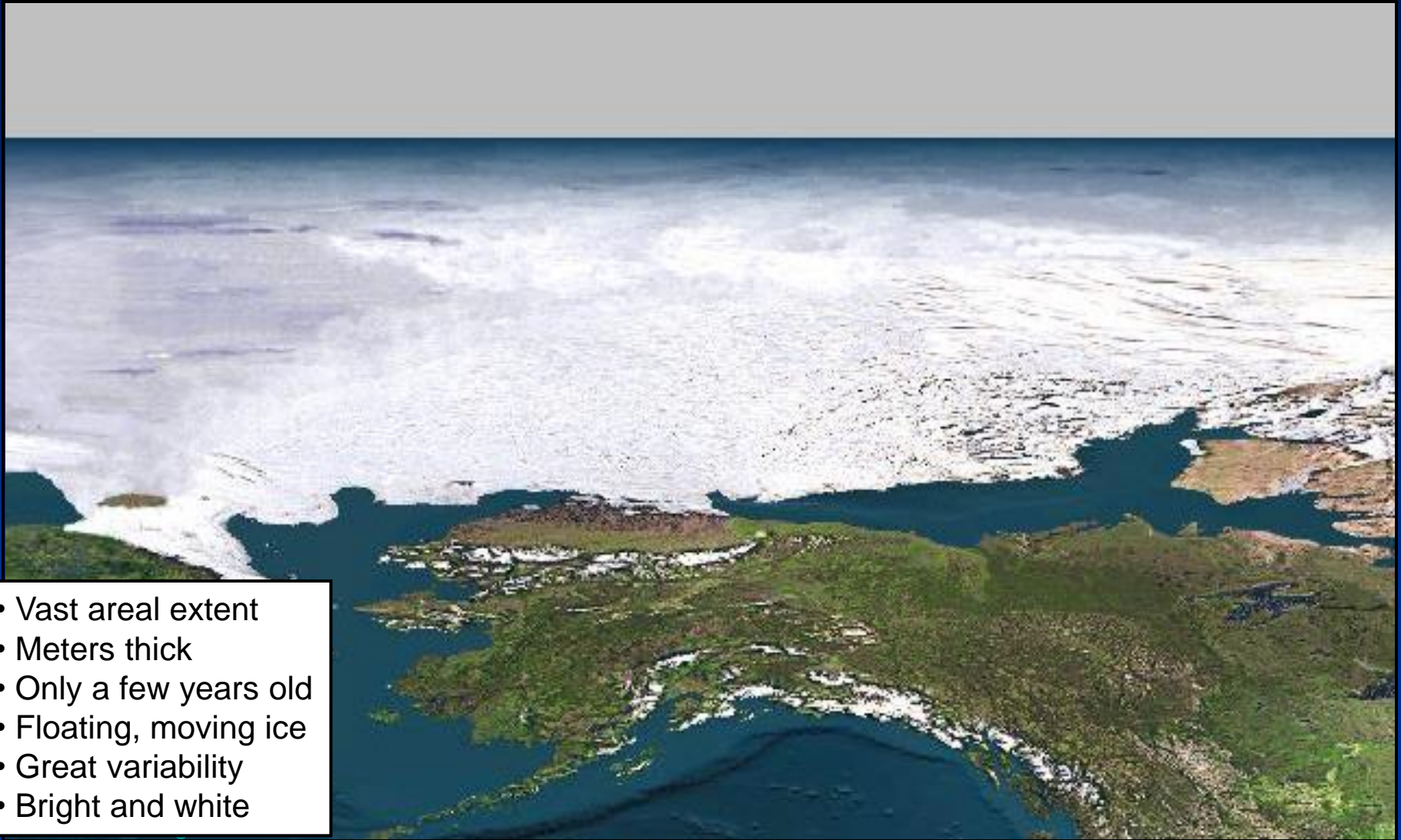
The golden age of Arctic exploration

Intergovernmental Panel on Climate Change Predictions for 2090 “business as usual”

- significant warming
- most pronounced in the Arctic



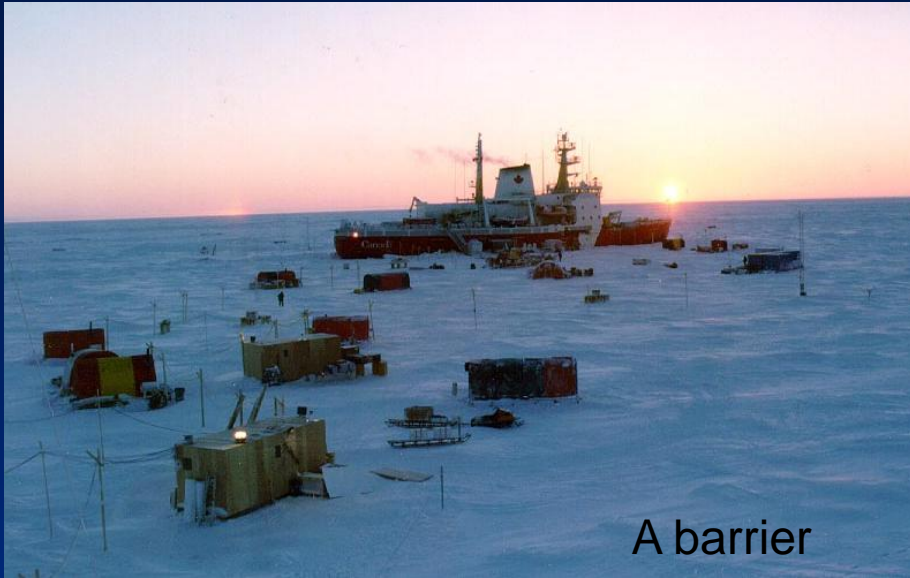
The Arctic sea ice cover



- Vast areal extent
- Meters thick
- Only a few years old
- Floating, moving ice
- Great variability
- Bright and white

The frozen ocean at the top of the world

The Arctic Sea Ice Cover



A barrier



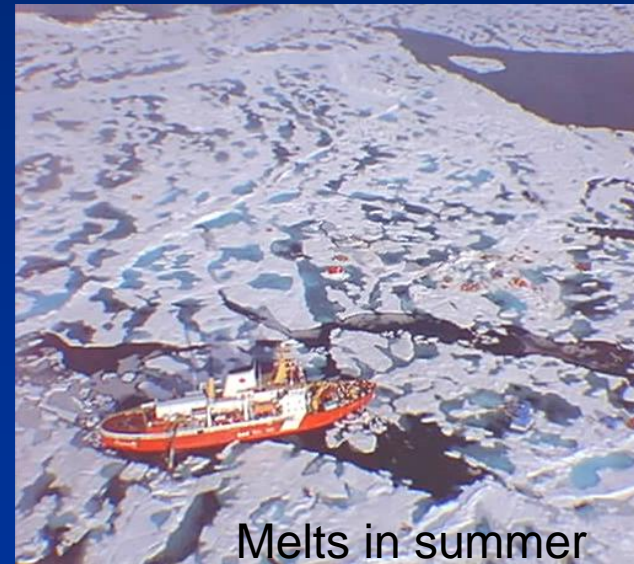
Blowing snow



Comes together



Freezes in winter

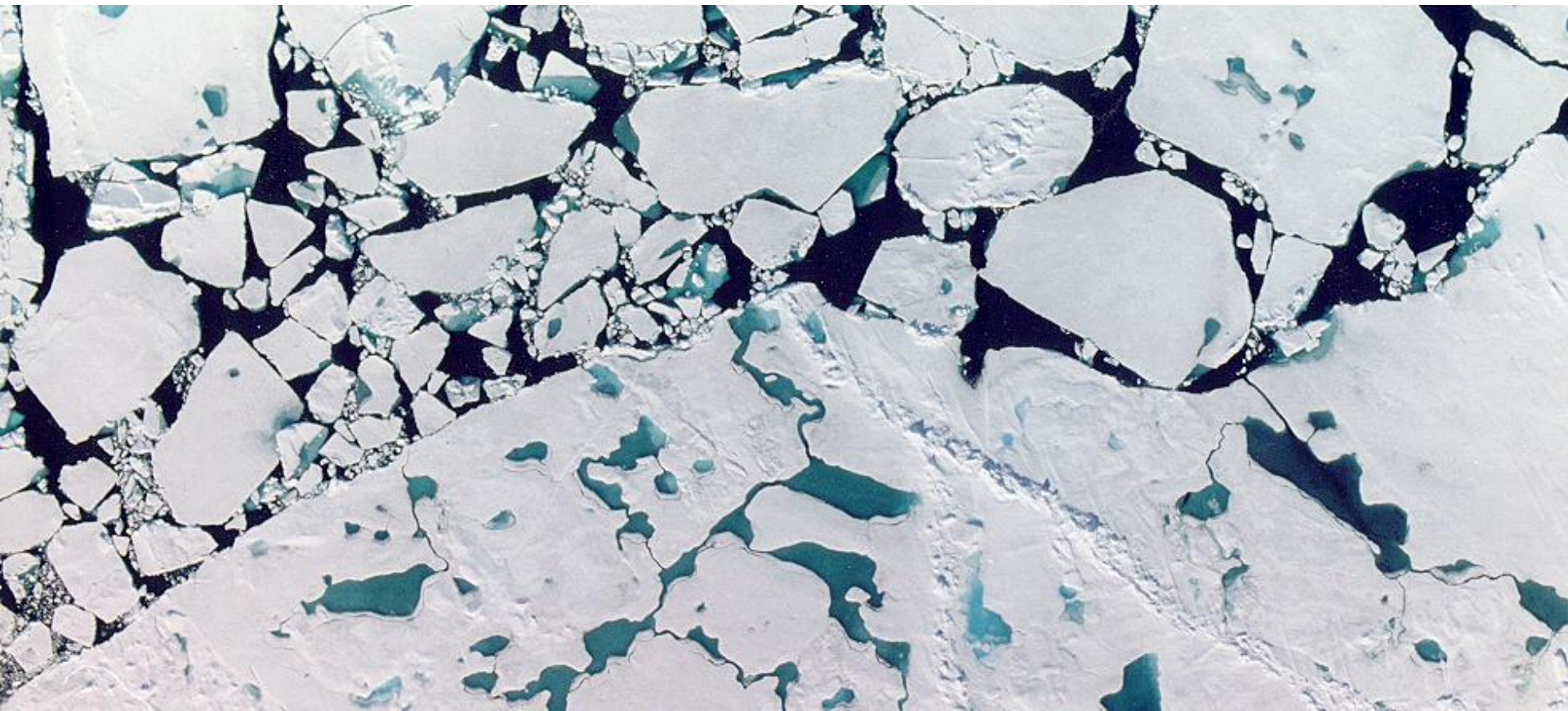


Melts in summer

An indicator and amplifier of climate change

How can you measure area of ice ?

- Ship records?
- Traditional knowledge?
- Satellites?
- Expeditions?
- Epic sagas?
- Charts?



Sea ice extent: satellite surveys

- Satellites have been monitoring since 70's
- Visible and infrared imagers
- Microwave - day, night, all weather
- Do a fine job of differentiating ice and ocean



Mission to planet earth

Ice extent – seasonal changes

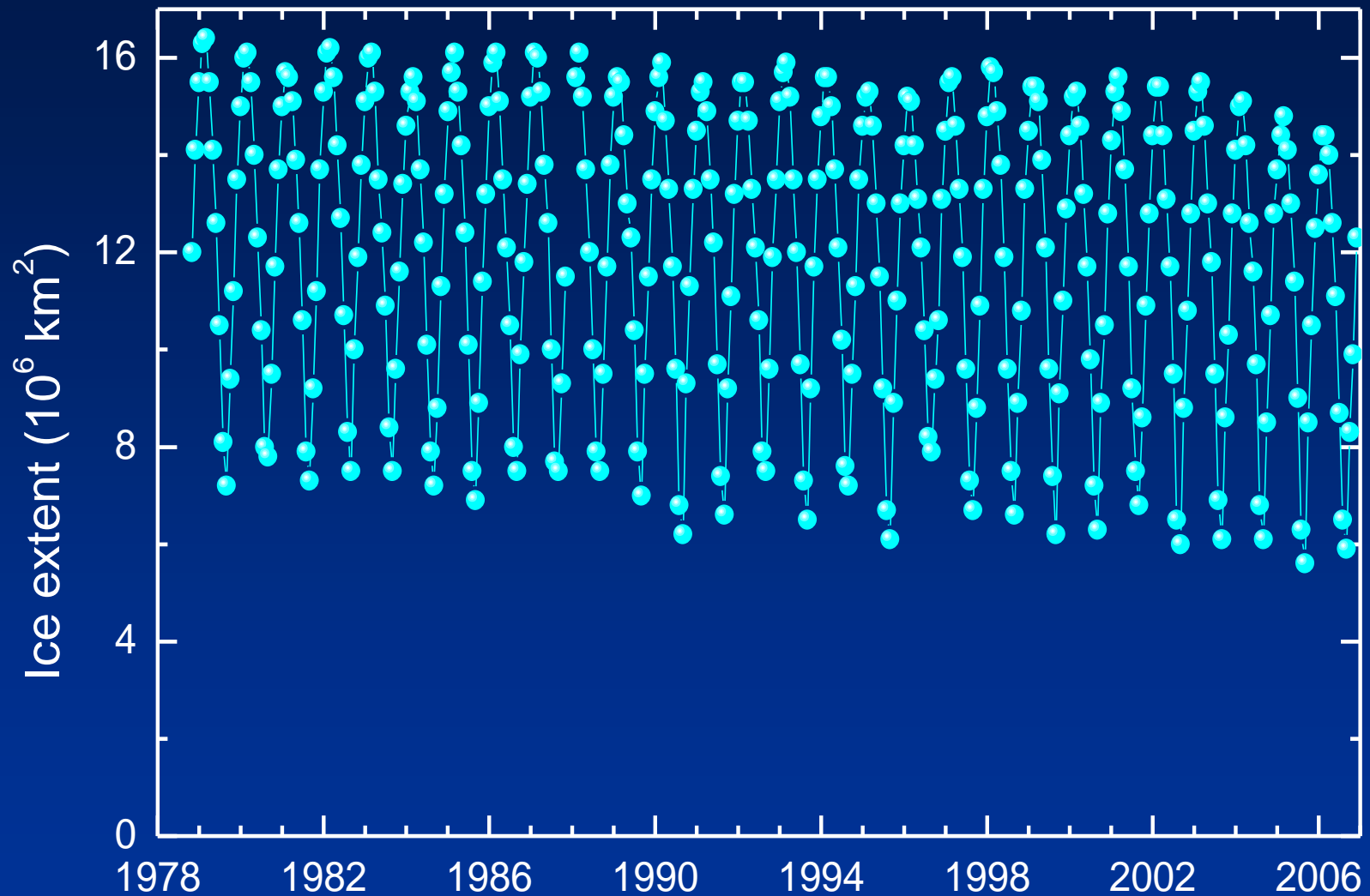


- 16.2 million square kilometers
- About size of continental US and Canada

- 7.5 million square kilometers
- About size of continental US

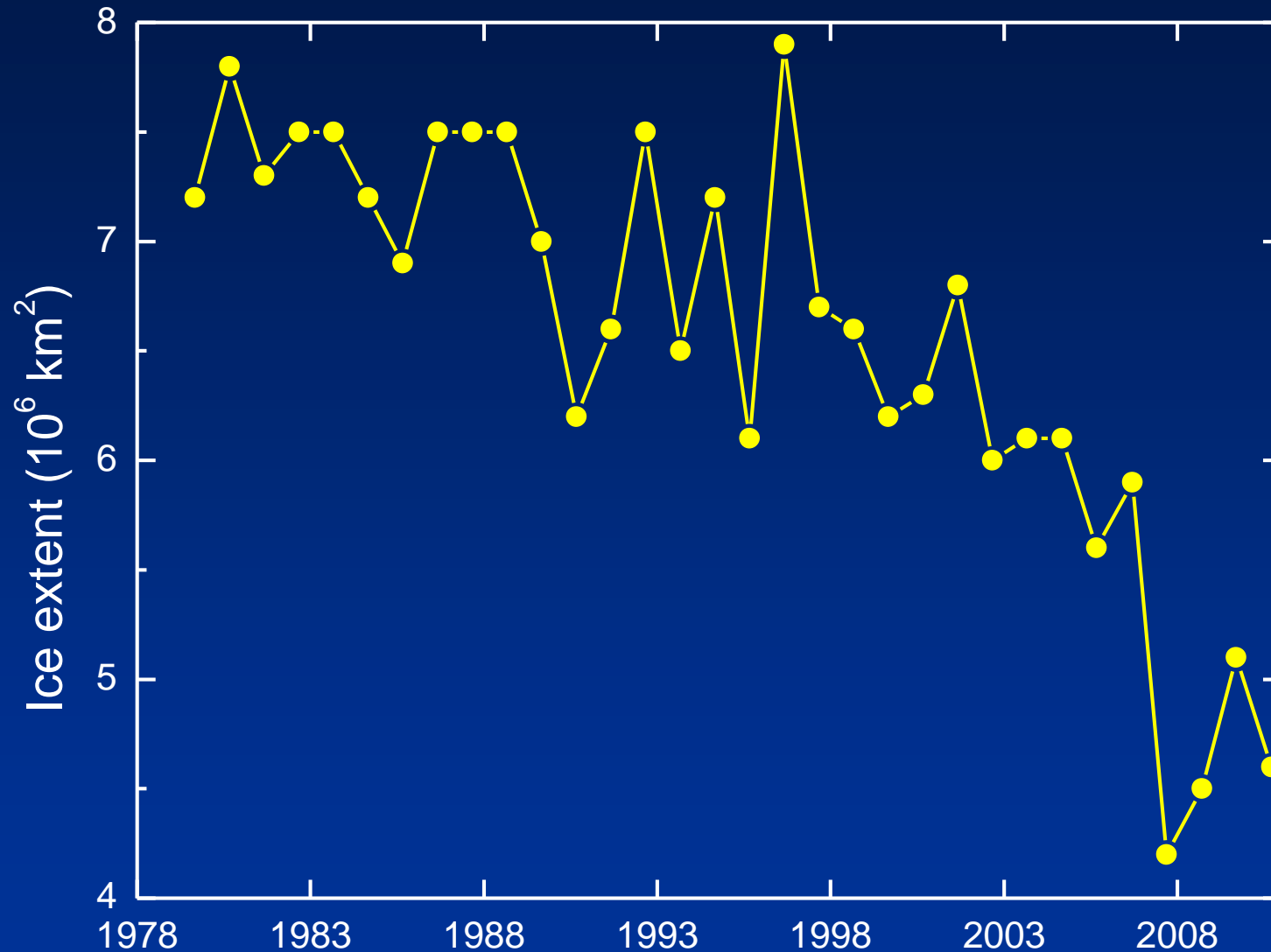
Areal extent varies by about a factor of 2

Sea ice extent



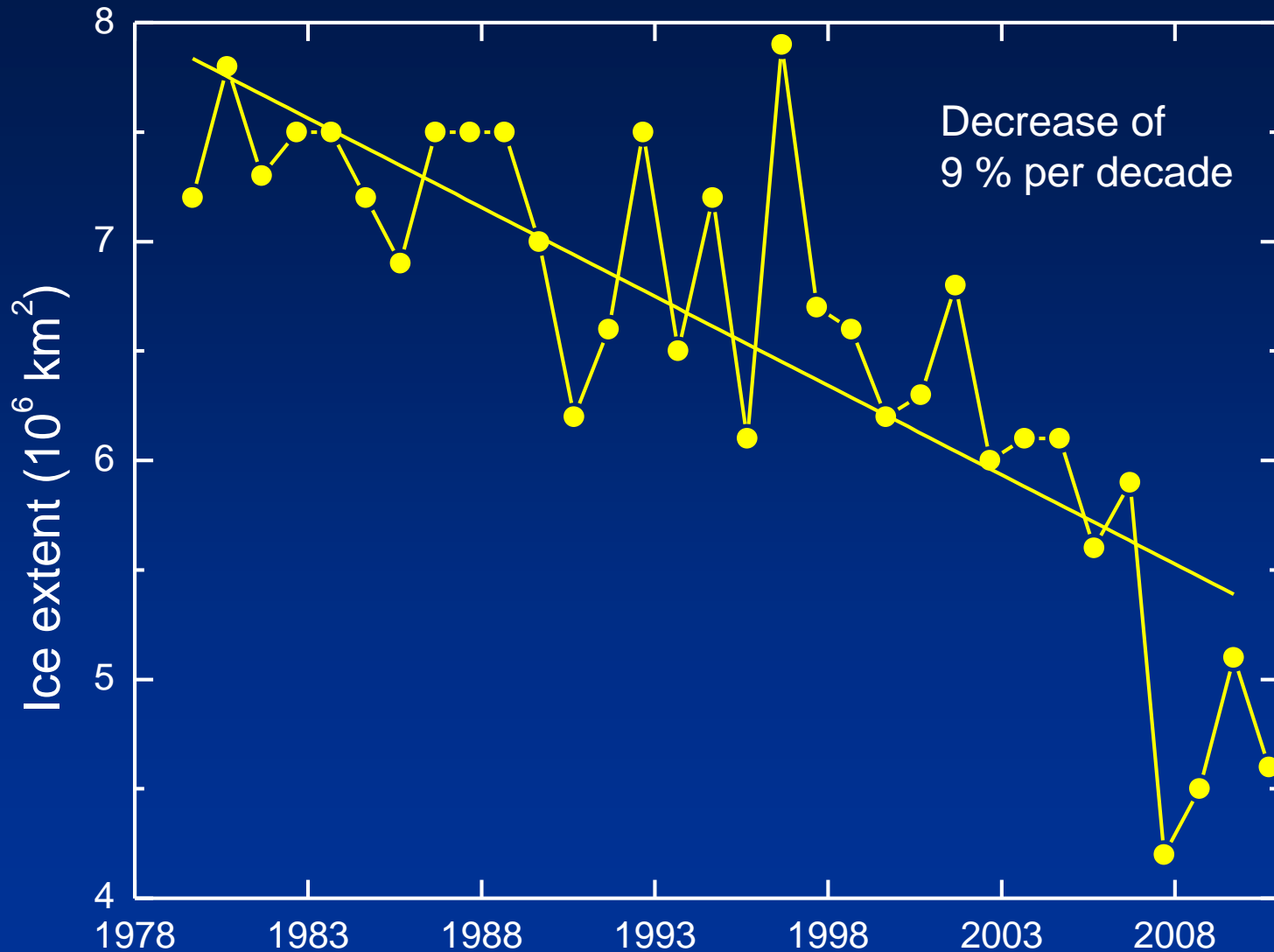
Major oscillations – looks complicated

Sea ice extent – September



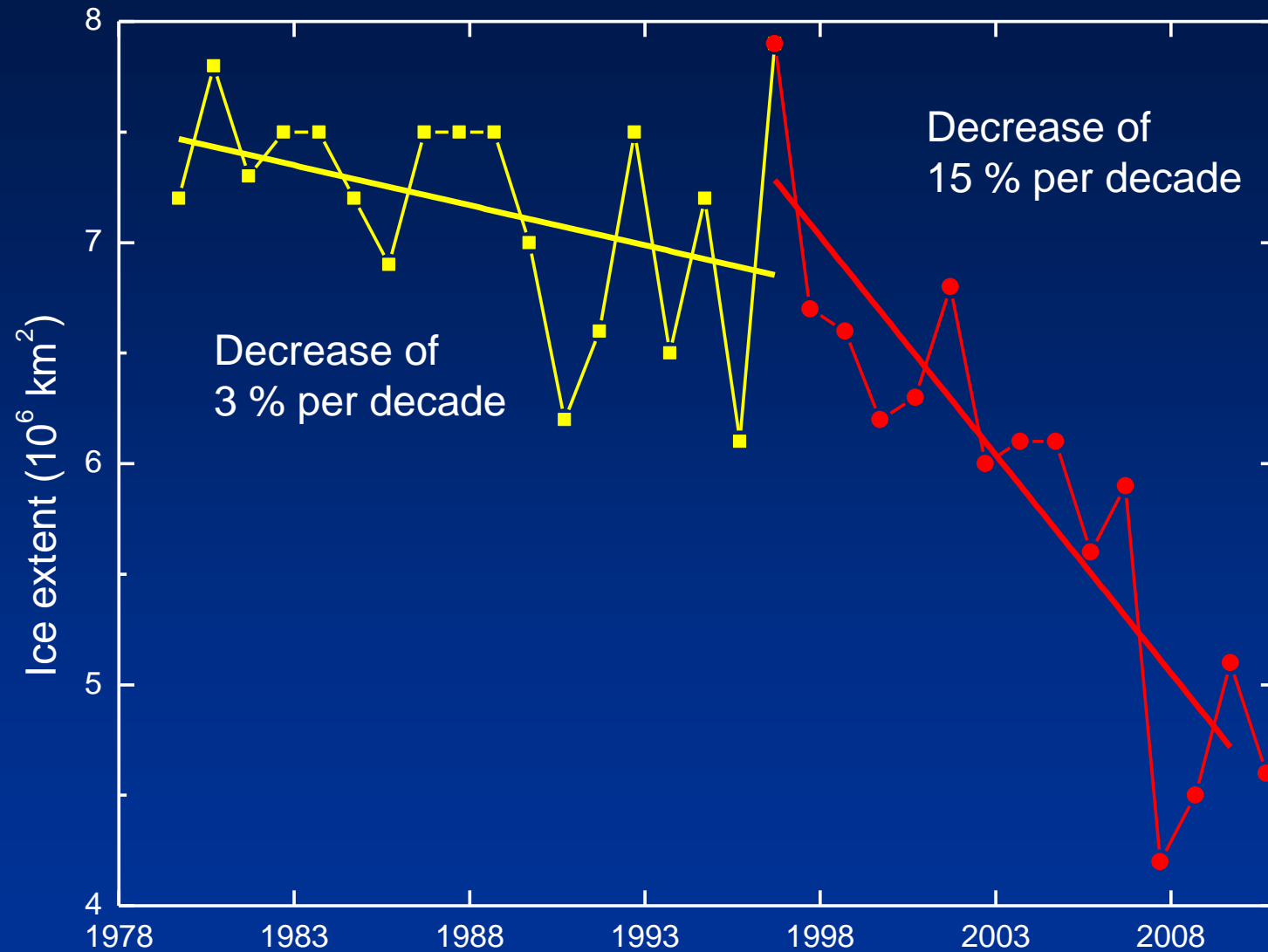
Downward trend, record low in 2007

Sea ice extent – September



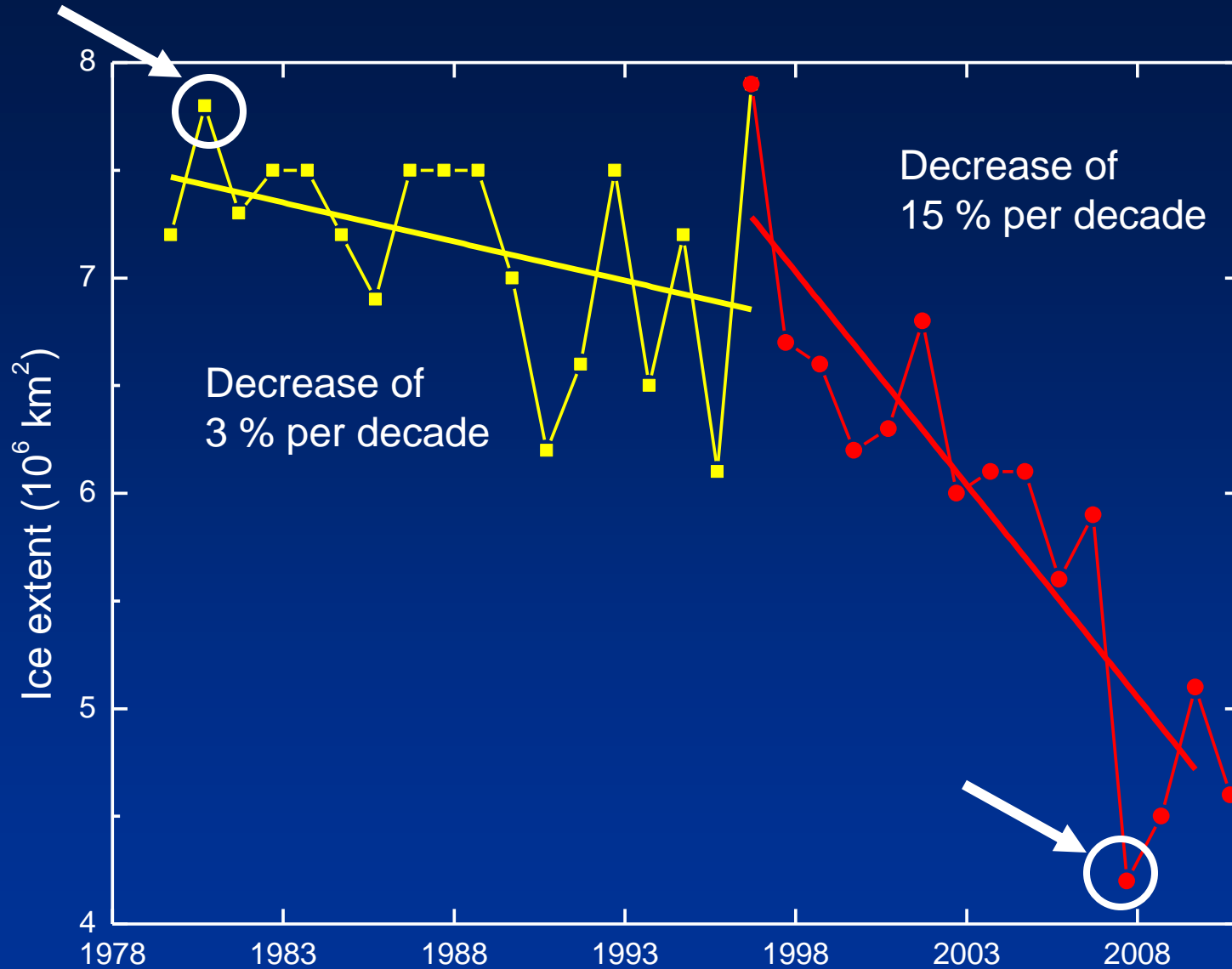
Downward trend, record low in 2007

Sea ice extent – September



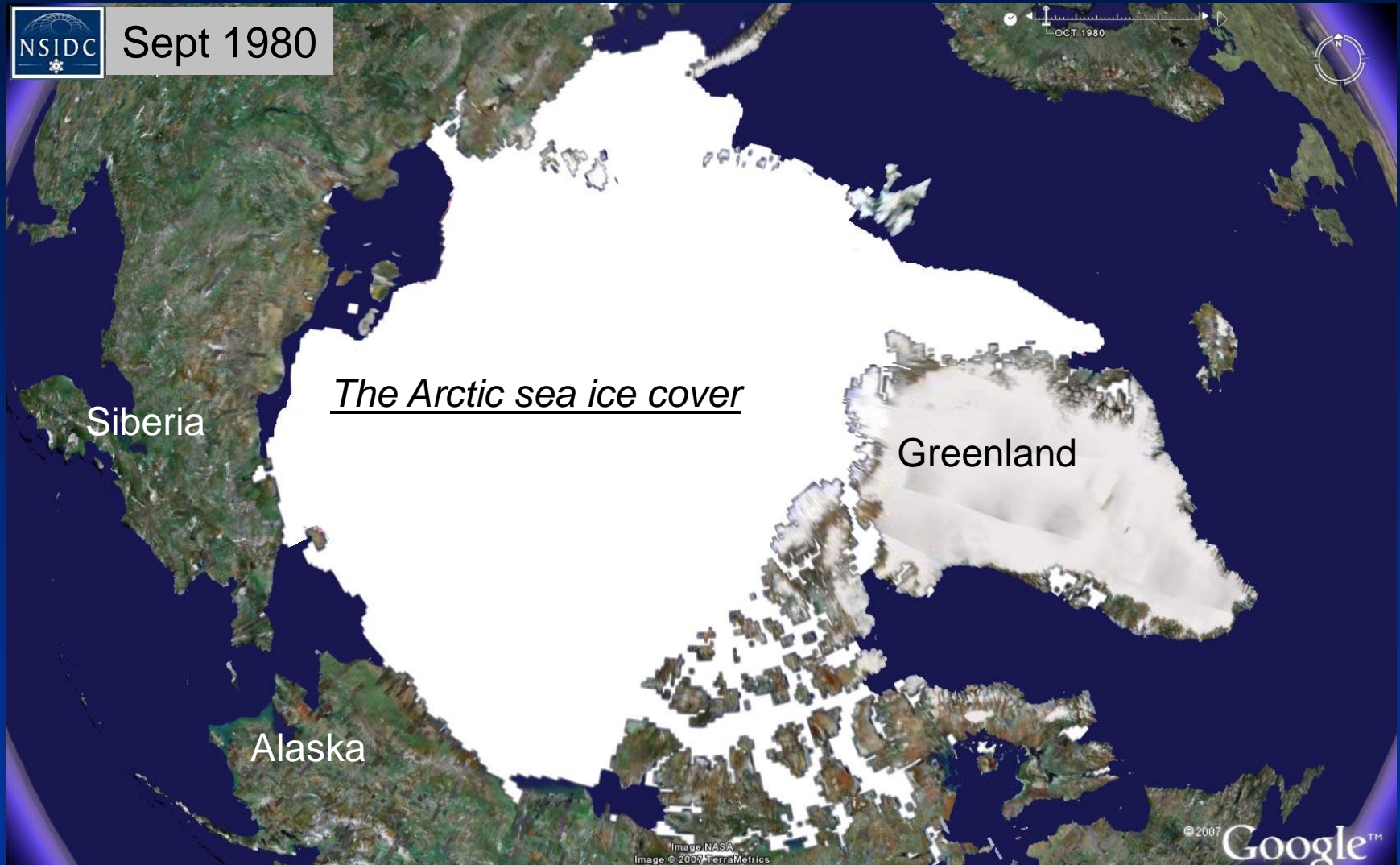
Downward trend is accelerating

Sea ice extent – September



Downward trend is accelerating

Changes in sea ice extent



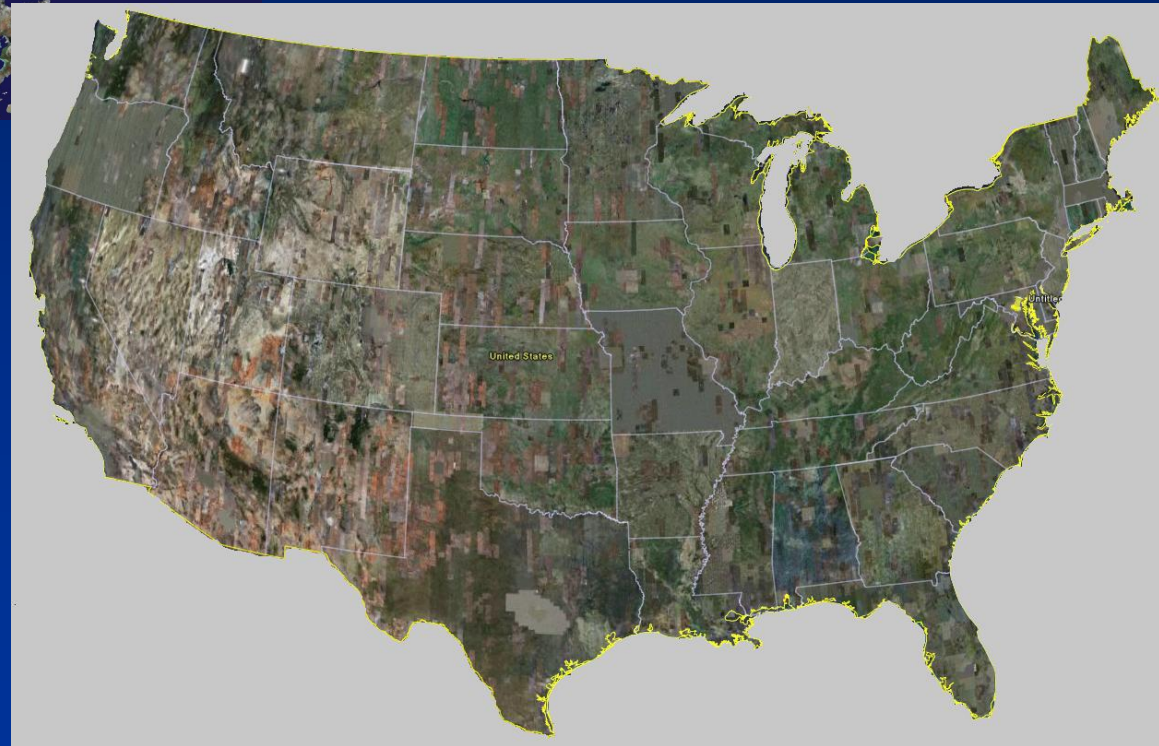
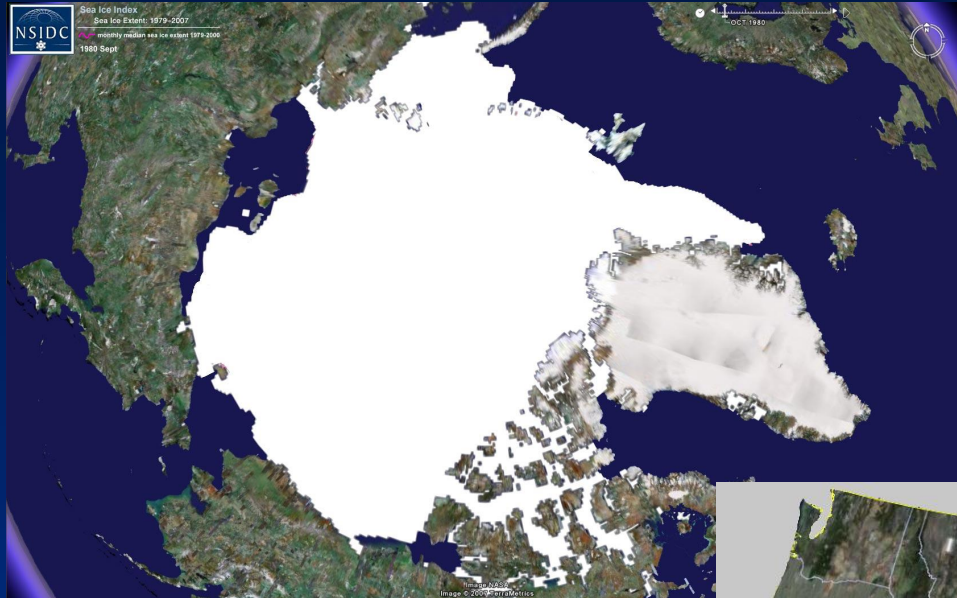
September 1980: 7.8 million square kilometers

Changes in sea ice extent



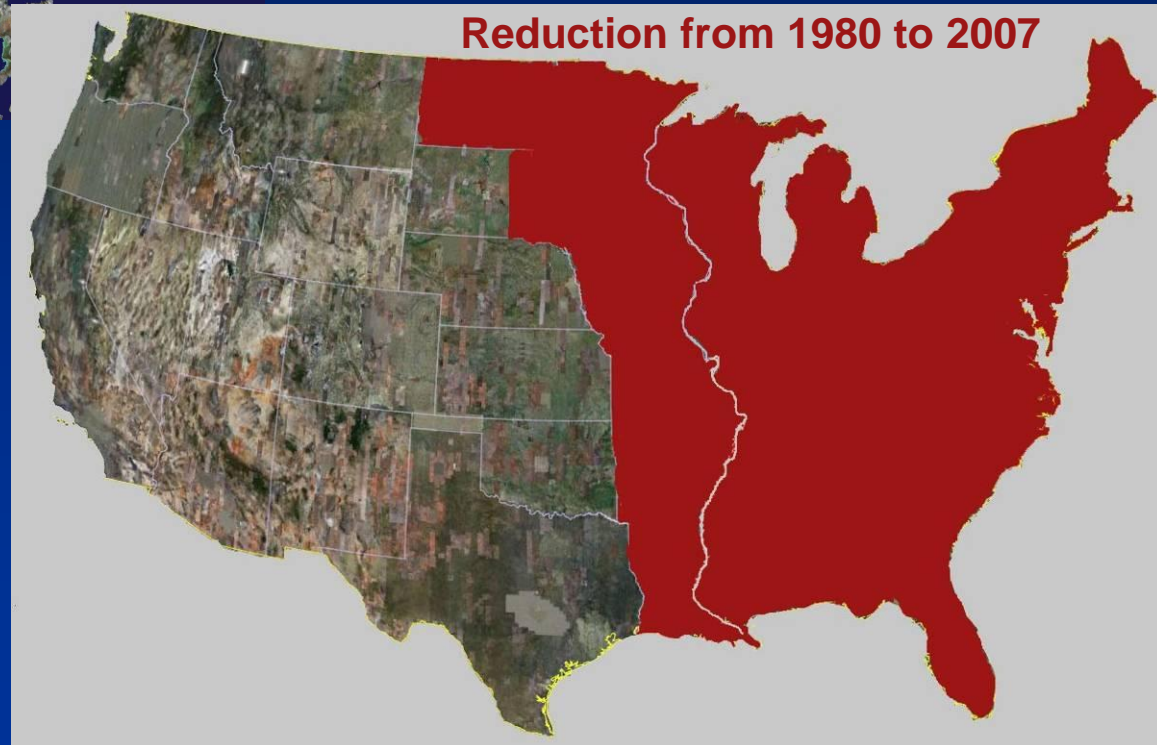
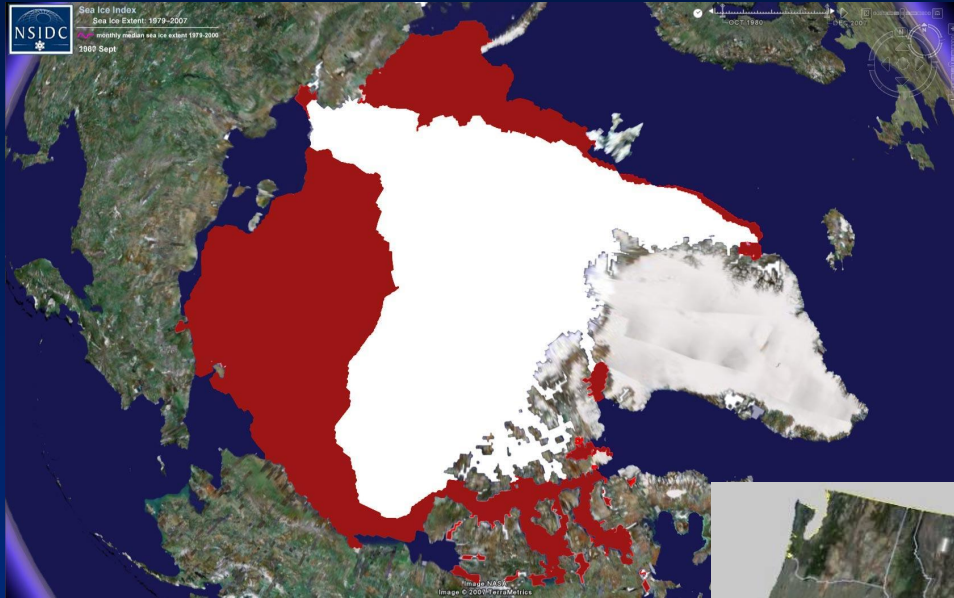
September 2007: 4.2 million square kilometers

Changes in sea ice extent



September 1980

Changes in sea ice extent

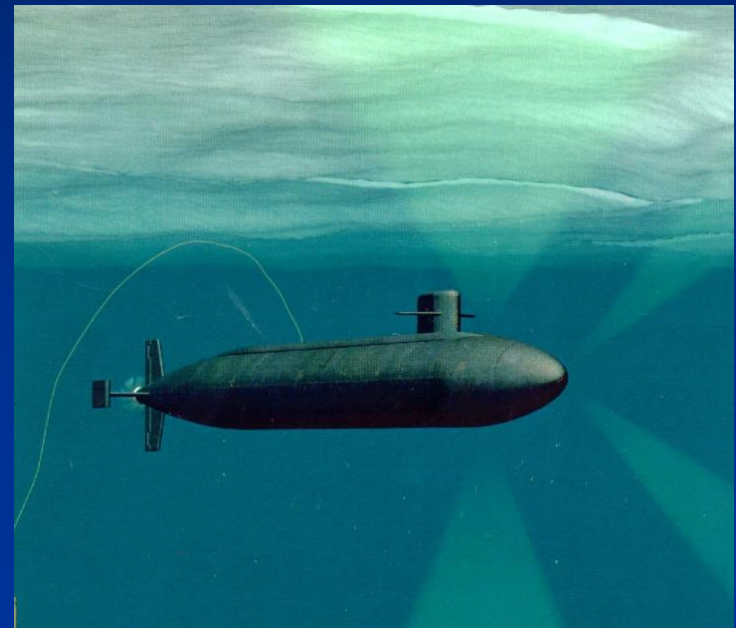


Huge decrease in ice extent

How thick is the ice?

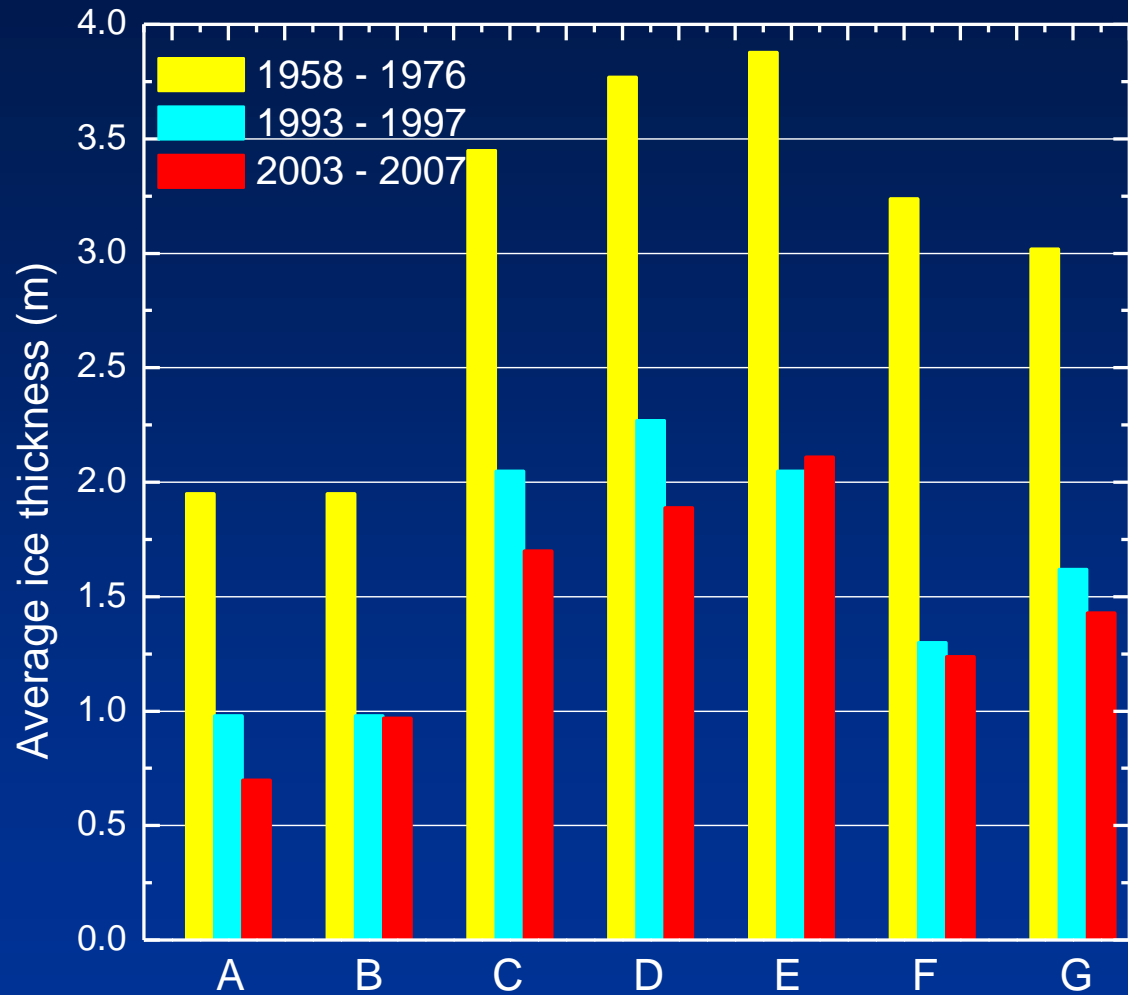


- Ice thickness from submarines
- Here and there...
- Every so often...
- Consider 7 regions
- Three time periods:
 - Good old days (1958 – 1976)
 - The nineties (1993 – 1997)
 - Past decade (2003 – 2007)



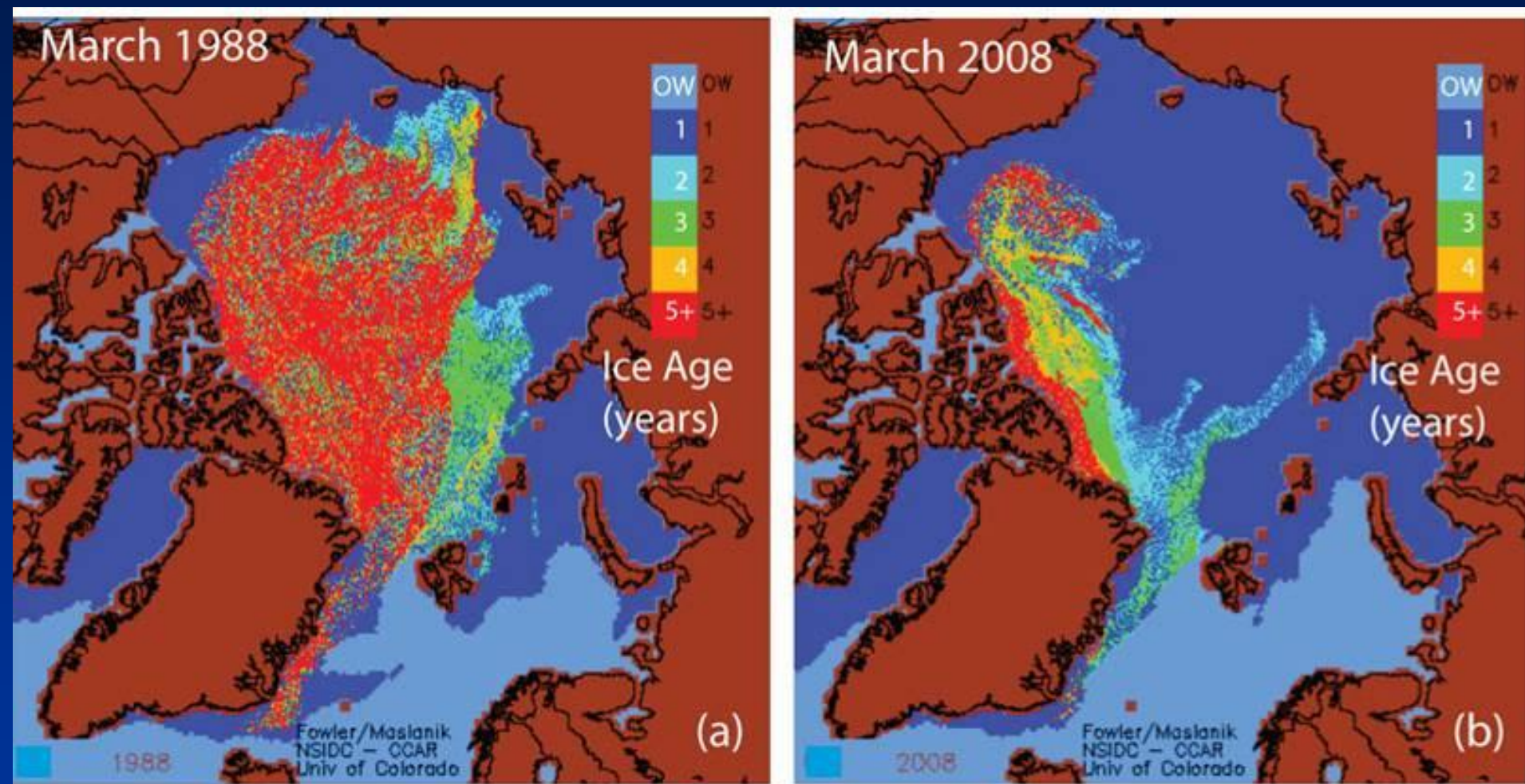
Best historical record is from submarines

How thick is the ice?



Thinner than it used to be

How old is the ice?



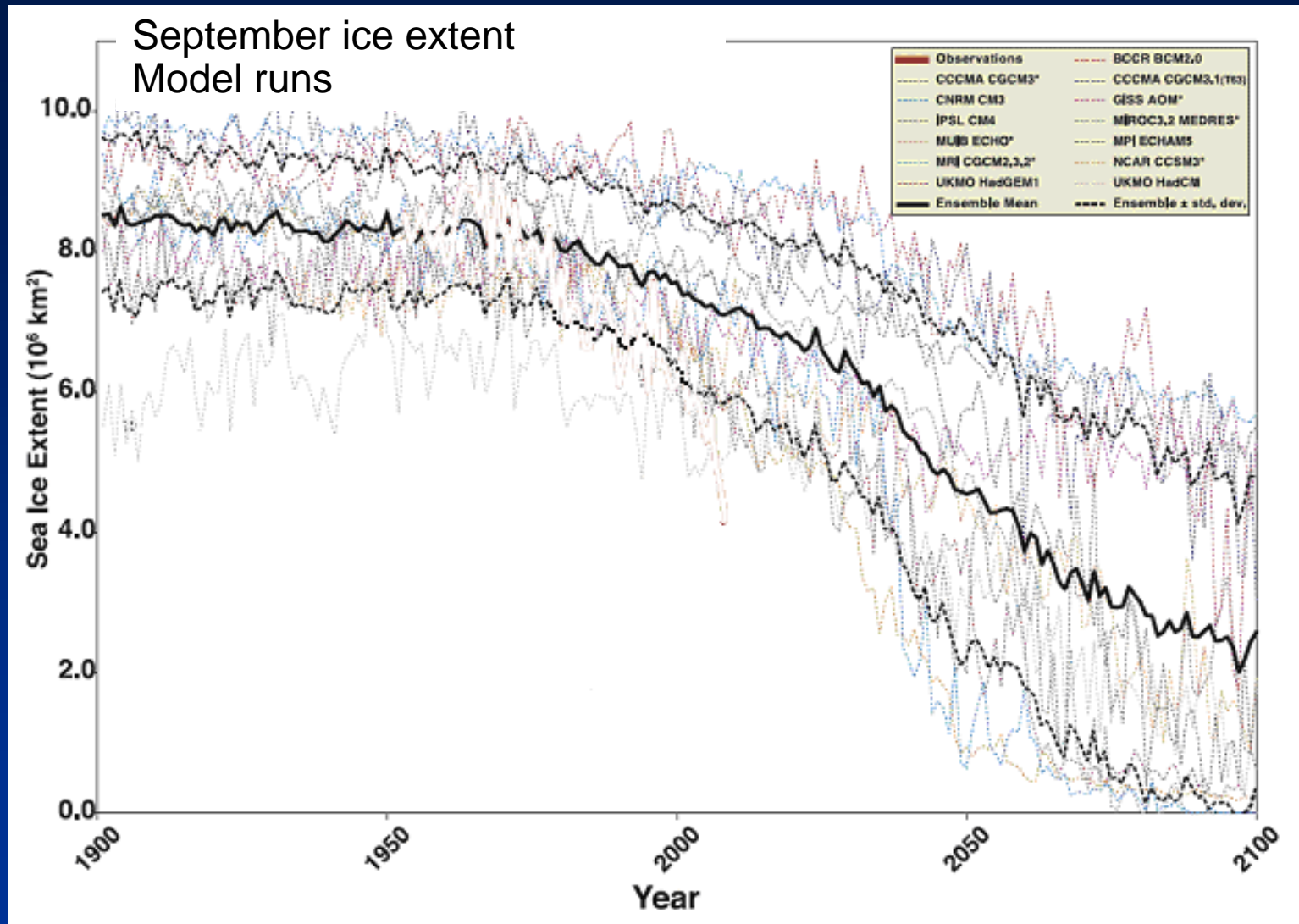
Younger than it used to be

Observations show sea ice is melting



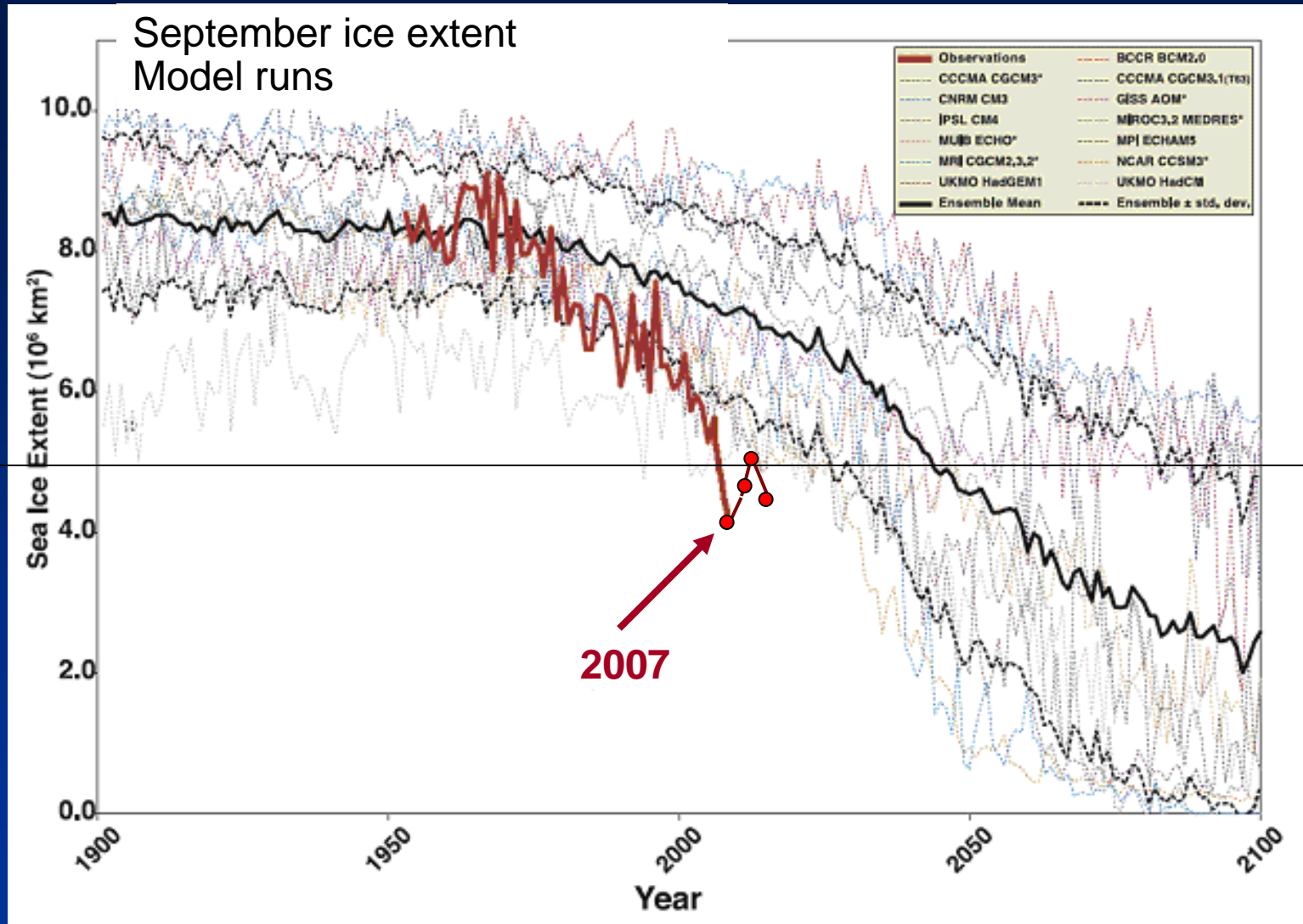
Ice area is small, ice is thinner and younger

What about the future?



Models predict decline in ice extent

What about the future?



Stroeve et al. 2007

Observationed decline is faster! But why?

The Ice-Albedo Feedback: An Amplifier of Climate Change



The ice strikes back!

What is the albedo?

Al Bedo – famous chef

Albedo – measure of cloudiness

Albedo – a small Pacific island

Albedo – great name for a child

Albedo – temperature of the planet

Albedo – Rock group

$$Albedo = \frac{\int_0^{2\pi} \int_0^{90} R \cos \theta d\theta d\phi}{\int_0^{2\pi} \int_0^{90} I \cos \theta d\theta d\phi}$$

My favorite geophysical parameter

Albedo

incident sunlight



Albedo

Albedo = $\frac{\text{reflected sunlight}}{\text{incident sunlight}}$

Nothing reflected = 0
All reflected = 1



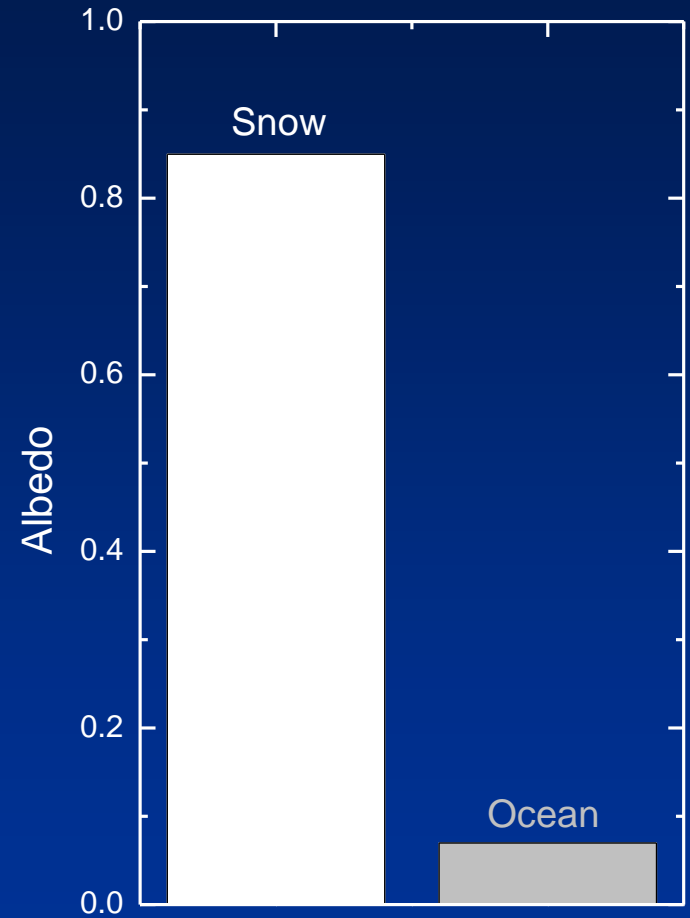
Albedo is fraction of sunlight reflected

Ice albedo feedback: amplifying change



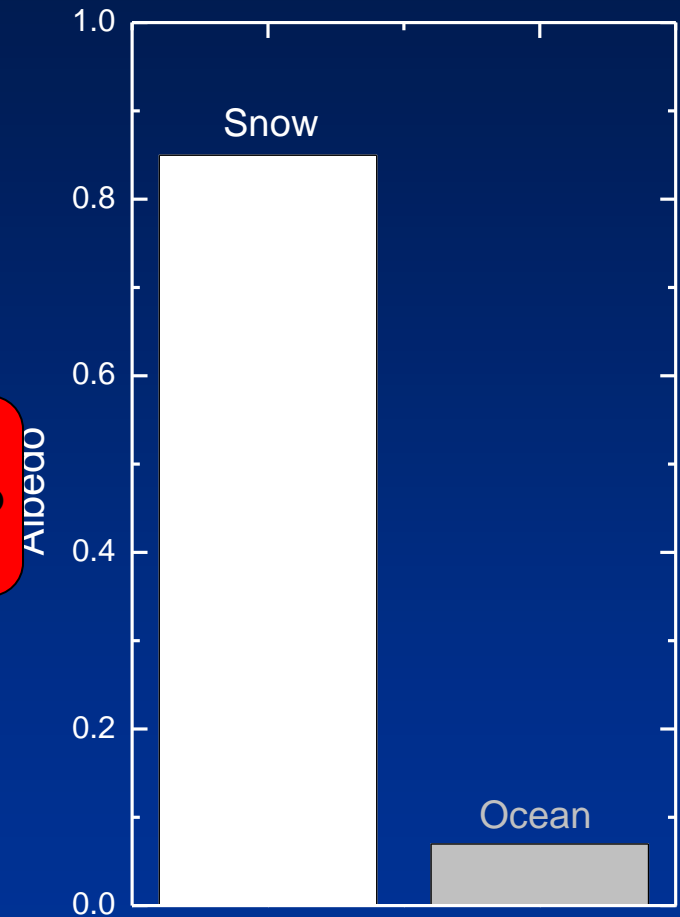
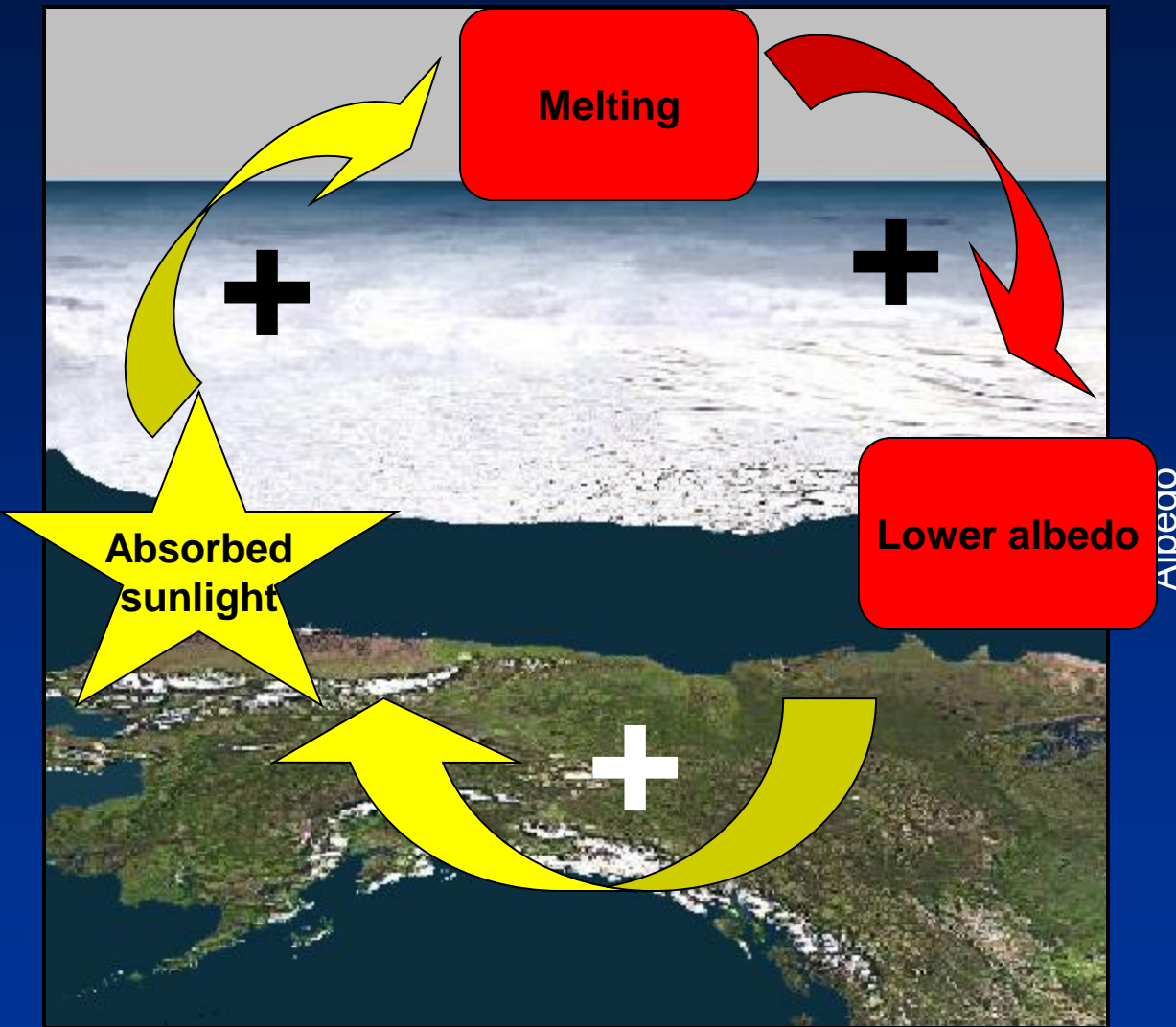
Sea ice in spring

Ice albedo feedback: amplifying change



Largest albedo to smallest

Ice albedo feedback: amplifying change



Largest albedo to smallest

Estimate of solar heating

Heat into ocean = Sunlight x Ocean area x (1 – albedo)

Input:

- Sunlight - models
- Ocean area - satellite
- Ocean albedo (α) = 0.07

Output:

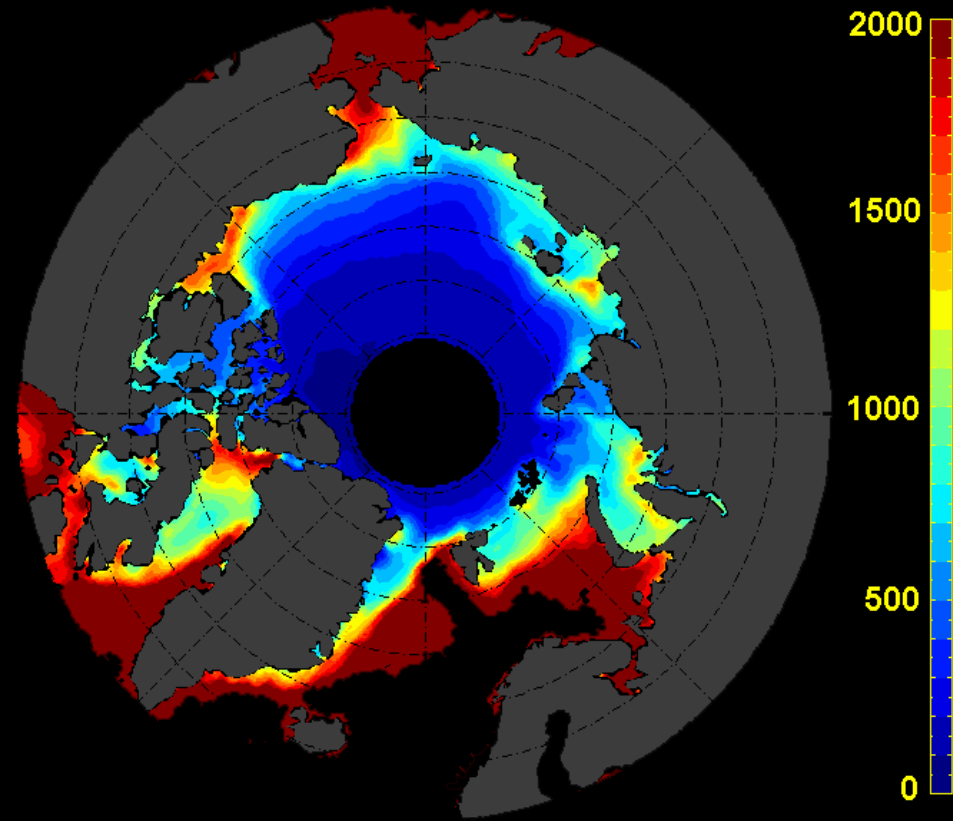
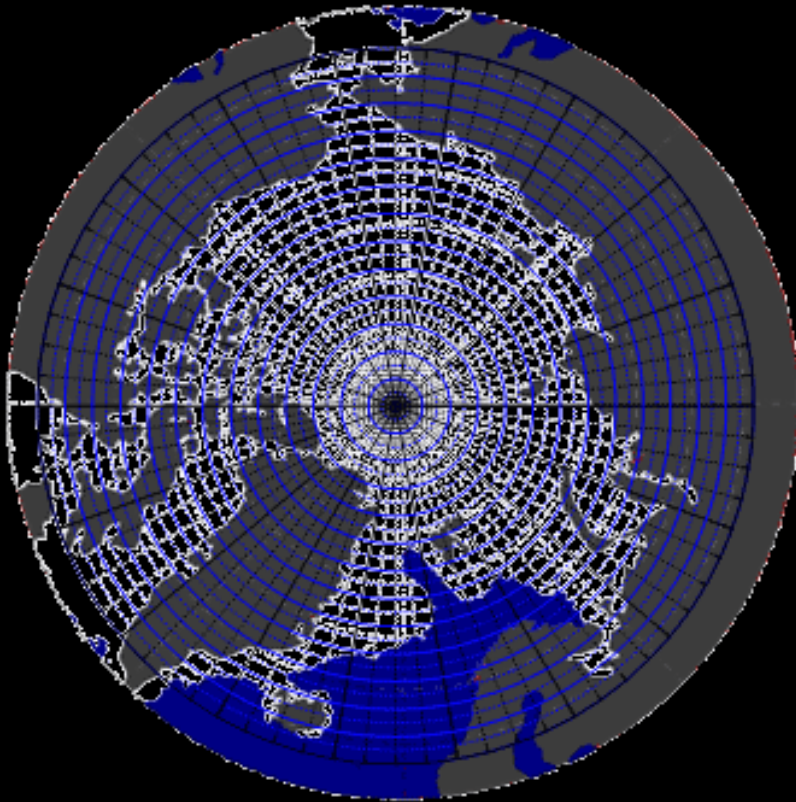
Sunlight absorbed to the ocean



Incident solar, ice concentration, and albedo -> heat input

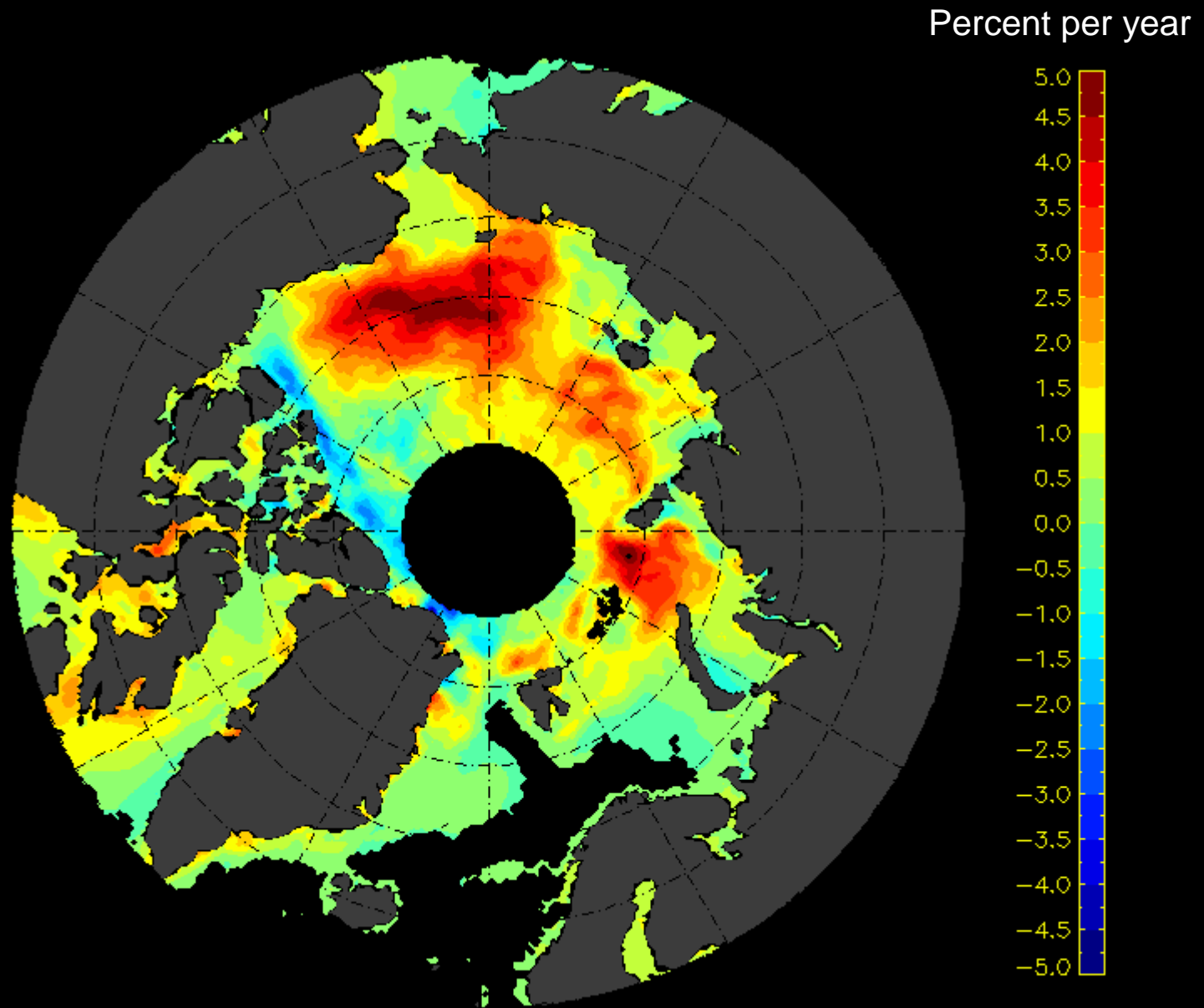
Region of Interest

- Everywhere there is ice (white area)
- 25 x 25 km grid
- 25,000 grid points
- Every day from 1979 to 2007
- Compute input to ocean



Heat input over the Arctic Basin...from 1979 to 2007...daily

27 year trend of annual ocean solar heat input



Increasing solar heat input in 90% of area

The state of the ice cover

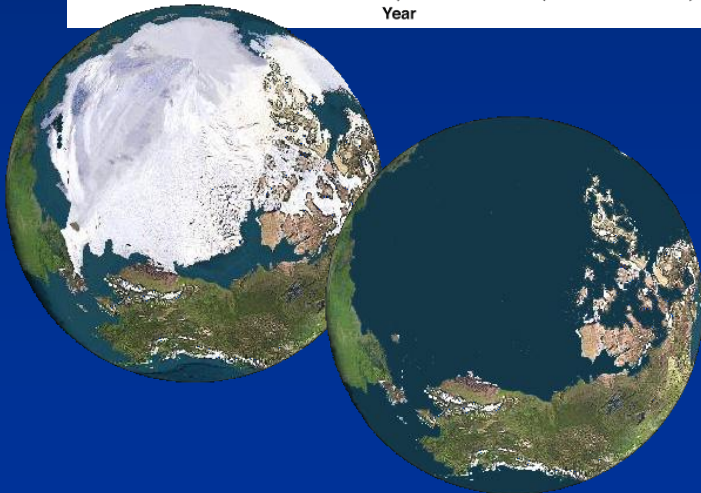
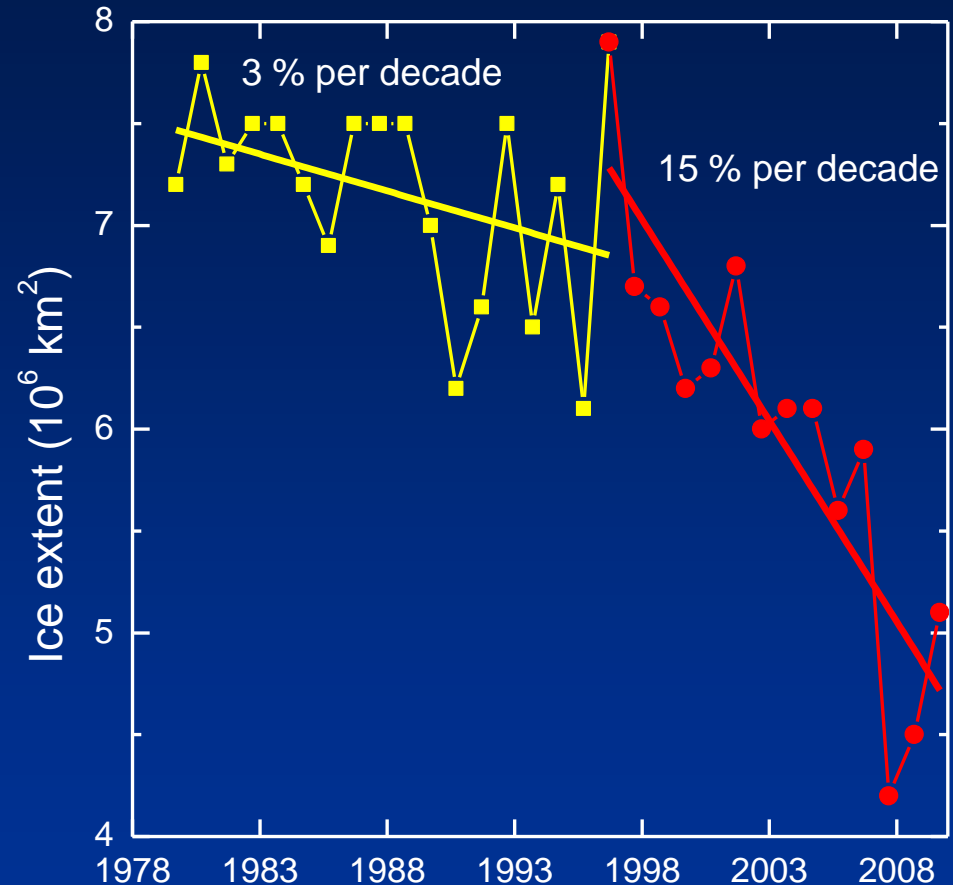
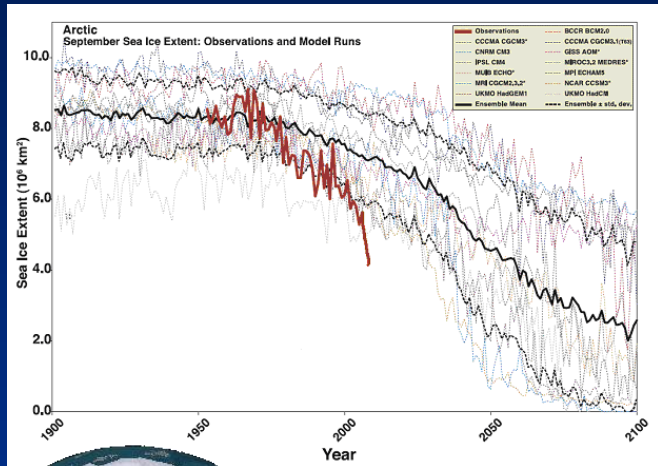
- The sea ice cover is in decline
- Ice albedo feedback is contributing
- Changes are faster than predicted
- The fundamental nature is changing



But what of the future?

Issues for a changing climate

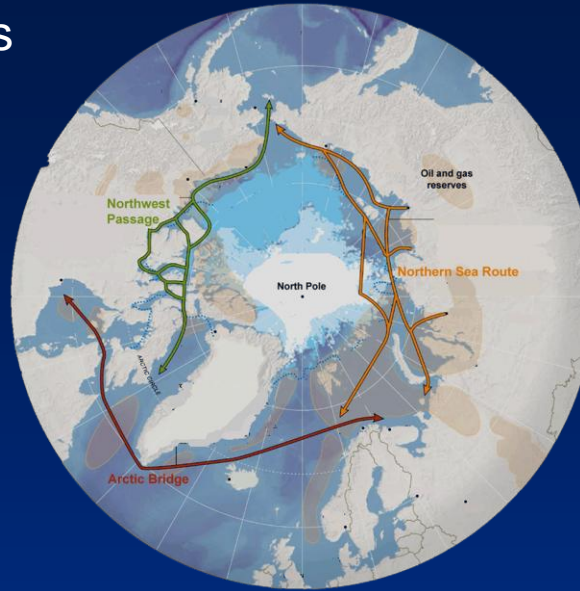
How much warming?
How fast will it happen?
How will the ice change?



Will the Arctic be ice free in summer?

Not just an intellectual exercise

- Polar bear threatened species
- Coastal erosion
- A flag at the pole
- Tourism
- Resource exploration
- Marine transport
- Law of the sea
- Ice – free Arctic Ocean



The New York Times Europe

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

AFRICA | AMERICAS | ASIA PACIFIC | EUROPE | MIDDLE EAST

Russians Plant Flag on the Arctic Seabed

From left, RTR Channel via Associated Press; Reuters Television; Yakov Khalip

At left, one of two Russian submarines was lowered into the Arctic Ocean on Thursday. Television showed the two Russian submarines on the seabed to plant the flag, center. The ships were more than two miles under the Arctic ice cap.

The New York Times Science

[NYTimes.com](#) > [Science](#) > [Environment](#)

Under All That Ice, Maybe Oil

A photograph of a large, flat ice floe in the Arctic Ocean. A small boat is visible in the distance, and the ice is broken up by smaller floes.

There are consequences today

The Road Ahead?



Ice-free summers in foreseeable future

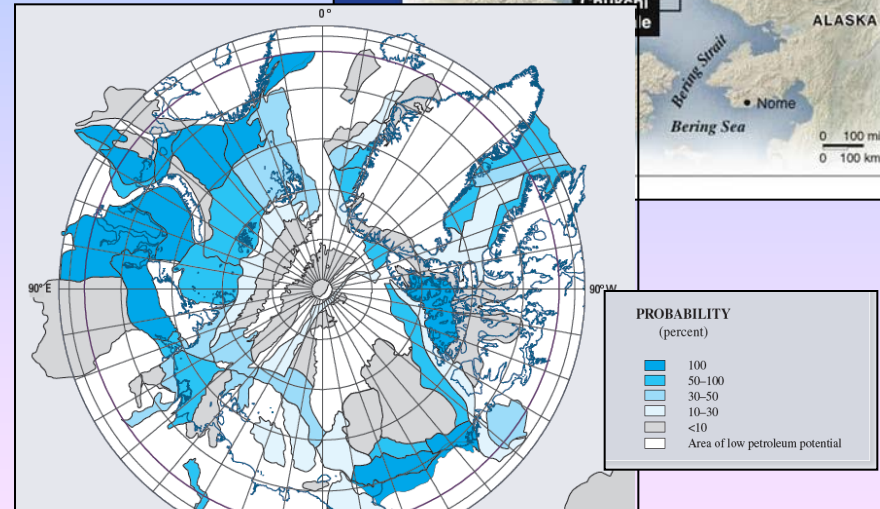
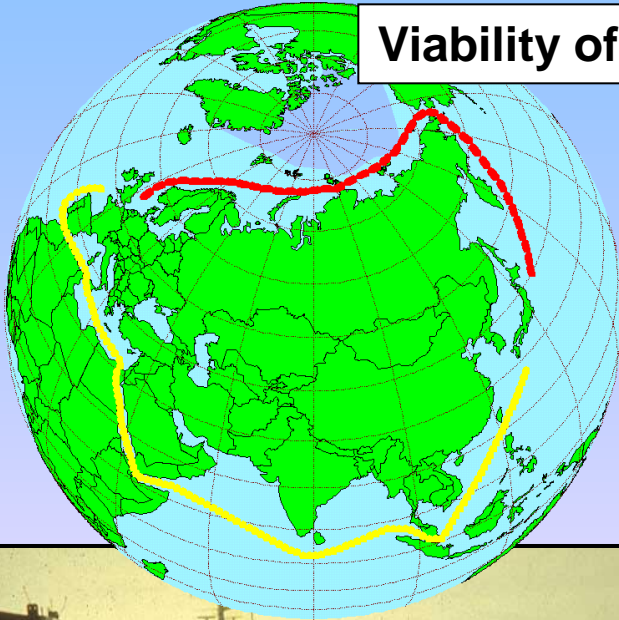
Sovereign Rights and Jurisdiction



- 1) North Pole 3) 200 nautical mile line 5) EEZ & CS Dispute
2) Lomonosov Ridge 4) Russian-claimed ECS

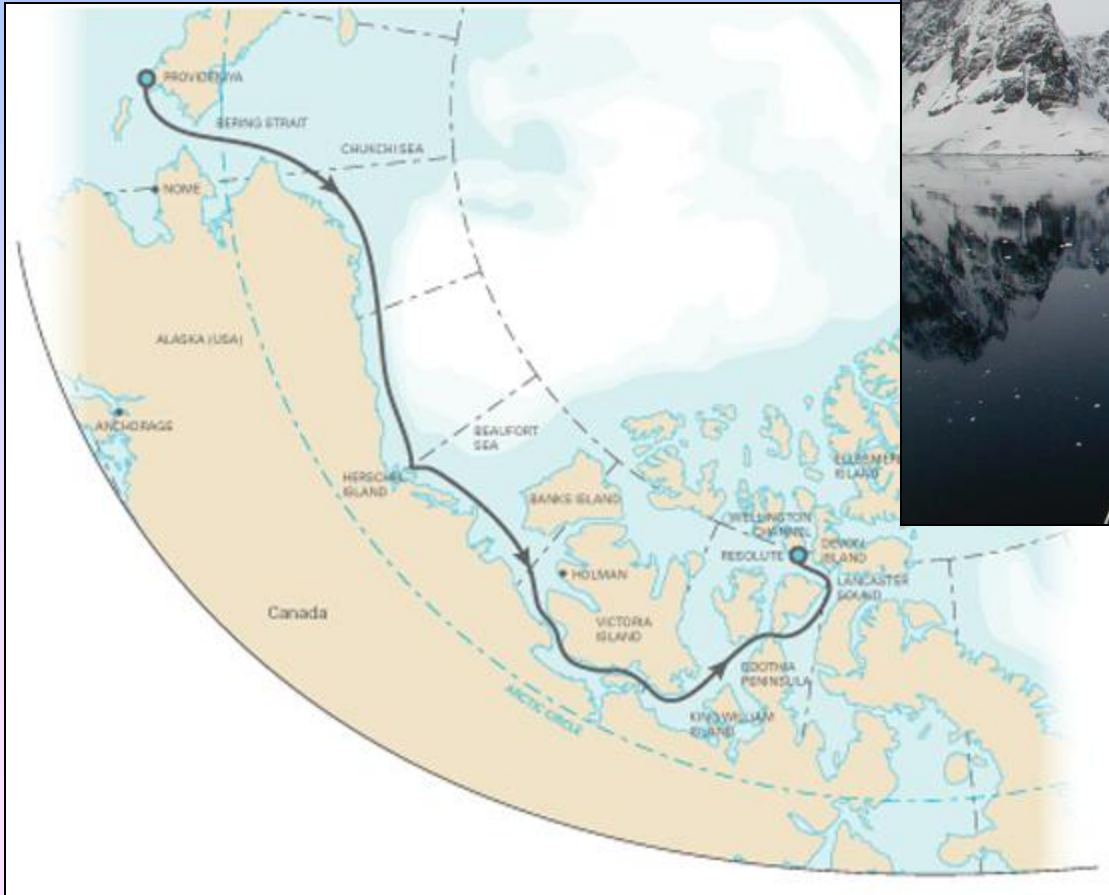
IMPACTS

Viability of Northern Sea Route



Economical access to natural resources

Increasing Tourism



TRANSITION ZONE

Ocean meets the land

Combination of more open ocean conditions and warming permafrost results in increased coastal erosion



Shoreline Protection System

Waves and Ice



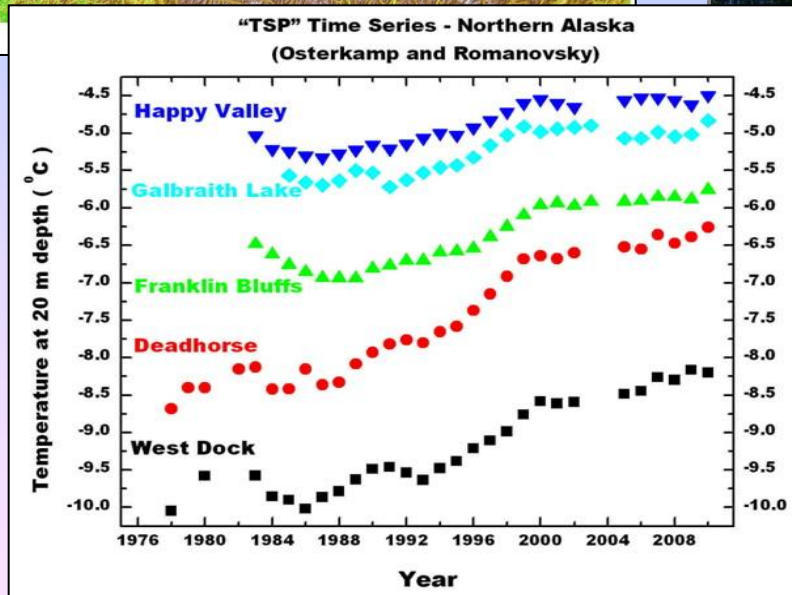
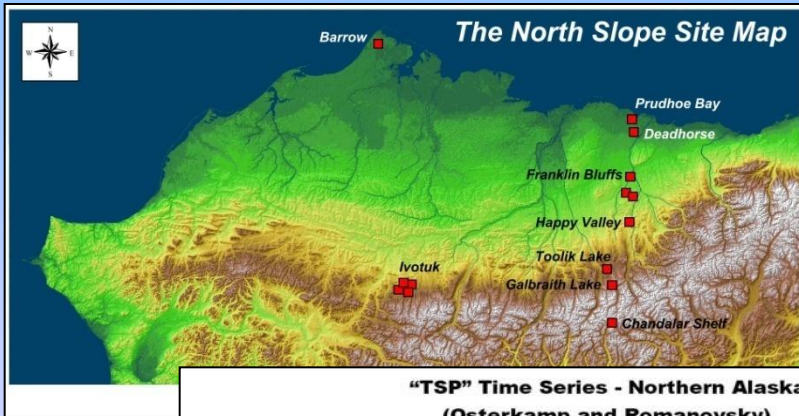
Ivu (aka Ice Shove)



WHAT ABOUT THE LAND?



Permafrost Degradation

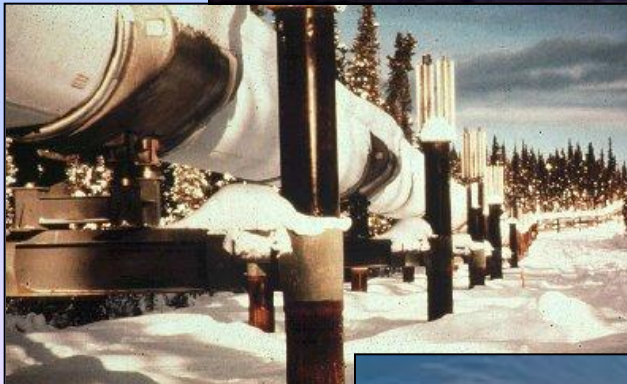


Substantial warming during last 20 years

IMPACT: *Differential settlement*



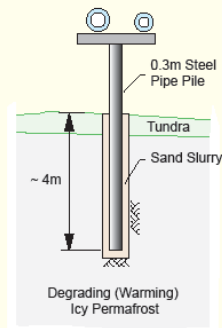
IMPACT: *Trans Alaska Pipeline*



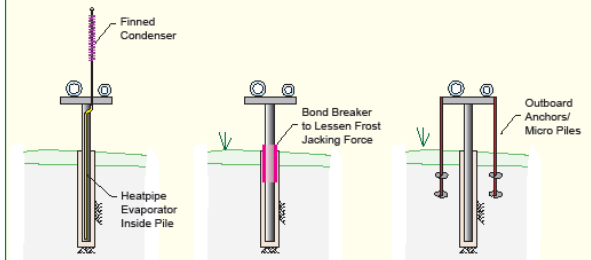
Pile Jacking

Cross-Country Adfreeze Piles to Support Pipelines

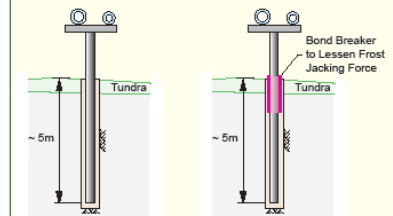
Typical Installation



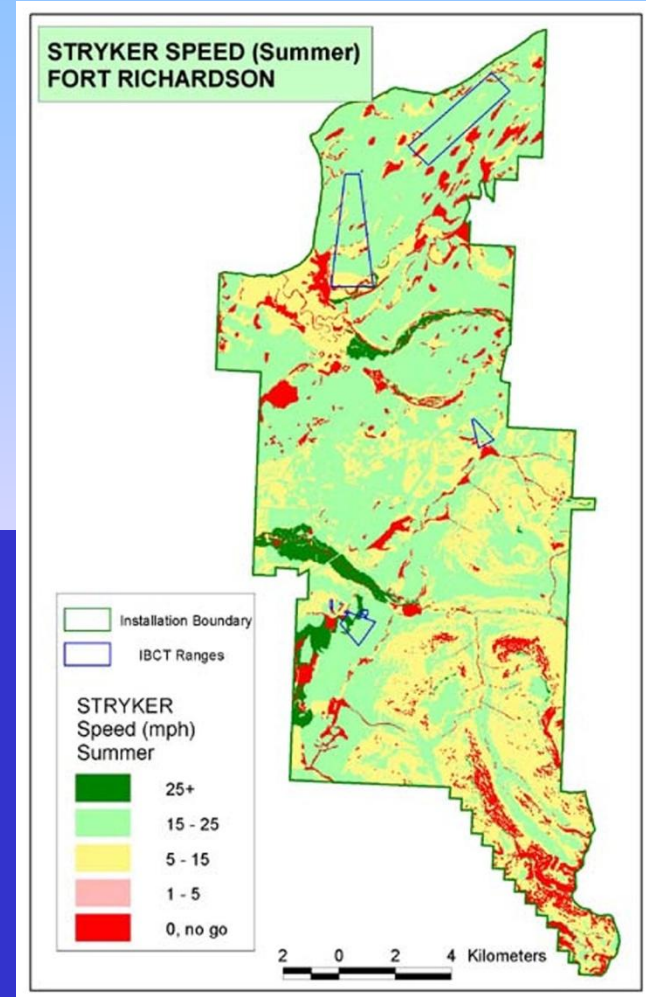
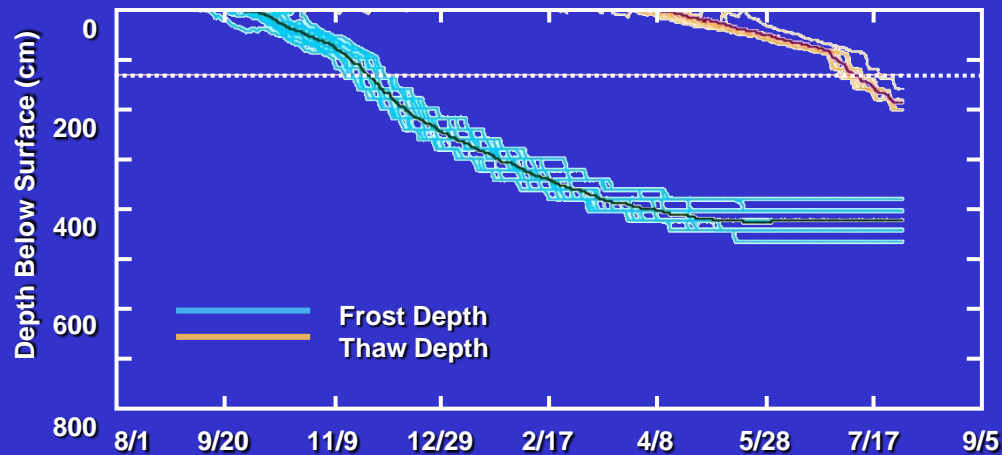
Retrofits to Arrest Settlement, Jacking or Leaning



New Installations



IMPACT: *Surface Mobility*



Decreased periods of tundra travel

IMPACTS: *A Way of Life*

- Shifts in the terrestrial and marine ecosystems
- Cultural changes for Native population



SUMMARY

(From a Polar Bear's Perspective)



**Challenges
galore!**

- Ice covers the Arctic, and its extent and future are uncertain due to climate change
- Recent observations of melting ice consistent with warming global temperatures
- Expect warming to continue throughout this century
- Impacts are significant in the Arctic



APLIS ICE CAMP 2007

Base of Operations



- **Alaskan Beaufort Sea**
- **200 miles North of Prudhoe**
- **1-1/2 hour plane ride**
- **Edge of perennial ice zone**
- **Multi-year ice floe**

APLIS 2007

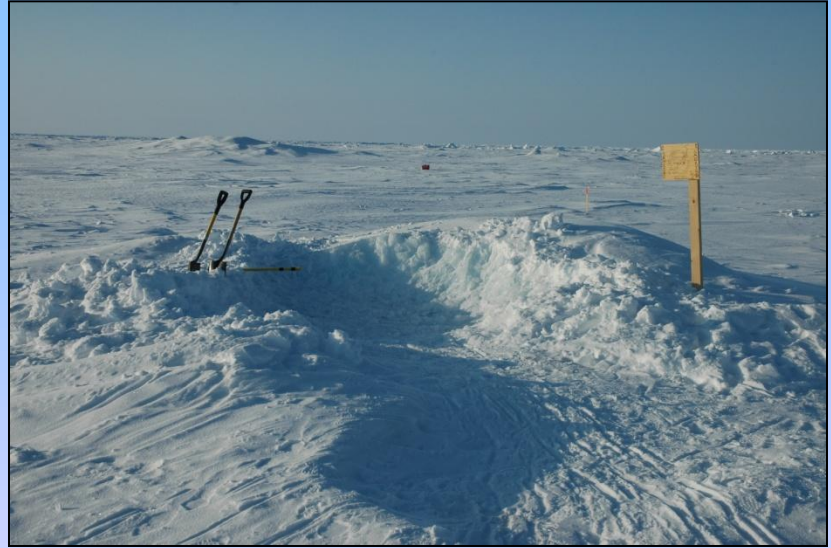


GETTING AROUND

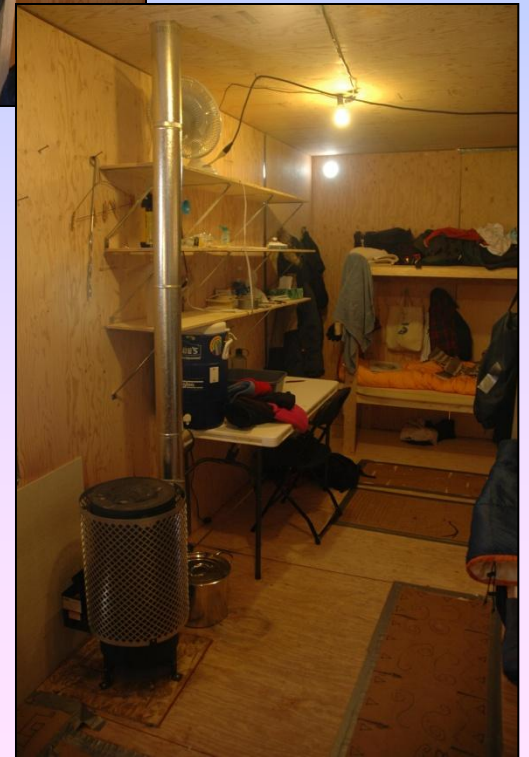


IN FROM THE COLD





HOME, SWEET HOME



FACES OF APLIS 2007



